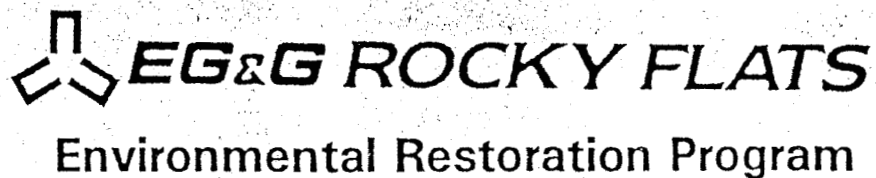


NOTICE

All drawings located at the end of the document.

DRAFT TREATABILITY STUDIES PLAN



September 21, 1990

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

A-SW-000020

WORK IN PROGRESS

Reviewed for
classification/UCR
H. M. Johnson
9/21/90

1/192

DRAFT TREATABILITY STUDIES PLAN



September 21, 1990

**U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado**

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AND 3
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- APPENDIX C TECHNOLOGY DATA SHEETS

EXECUTIVE SUMMARY

This Treatability Studies Plan (TSP) is part of a comprehensive, phased program of site characterization, remedial investigations, feasibility studies, and remedial/corrective actions currently in progress to address contamination at the Rocky Flats Plant. It was developed to meet the requirements of Article XI of the August 17, 1990 Draft Inter-Agency Agreement (IAG). The IAG is currently being negotiated and is expected to be finalized in the near future. The primary objective of the treatability studies program is to identify and evaluate technologies that are broadly applicable for remediating the various types of contaminants and media that exist at the Rocky Flats Plant. The program is not intended to demonstrate the ability of the investigated technologies to achieve specific clean-up goals or Applicable or Relevant and Appropriate Requirements (ARARs). Rather, the intent is to demonstrate, in general terms, whether or not the technologies should be further considered for specific problems at any of the 16 Operable Units (OUs).

The Treatability Studies Program is divided into two components which separately address practical (i.e., conventional) technologies and innovative/emerging technologies. The separation of the two programs allows immediate start on the testing of practical technologies and permits an orderly dealing with emerging technologies as they become available. Within this document, only the TSP for the practical technologies and the Practical Technologies Summary are presented.

This TSP provides background information on the Rocky Flats Plant (Section 2), a detailed discussion of program objectives (Section 3), and site contamination data (Section 4). The technology selection process (Section 5.1) is then described, followed by the Practical Technologies Summary (Section 5.2). The summary discusses the selection of target contaminants (Section 5.2.1) and the practical technologies and

applications (Section 5.2.2) considered. Also included in the summary is a detailed discussion of the selection of technologies for treatability studies (Section 5.2.3). Following the Practical Technologies Summary is the Future Treatability Study Work Plans. This section includes statements of work (Section 6.1) for each of the proposed treatability studies and guidelines for the preparation of future treatability study work plans (Section 6.2).

The next step in the program will be to prepare the Treatability Studies Work Plans for each of the proposed treatability studies under the sitewide program. These will be based on the work plan guidelines and statements of work. Upon satisfying National Environmental Policy Act (NEPA) requirements, the actual treatability studies will be performed, and a sitewide Practical Treatability Studies Report #1 (TSR) prepared.

A similar sitewide program will be carried out for the innovative/emerging technologies. This program will begin 1 to 2 months after completion of the Practical TSR #1.

The Treatability Studies Program as presented in this Treatability Studies Plan (TSP) is part of a comprehensive, phased program of site characterization, remedial investigations, feasibility studies, and remedial/corrective actions currently in progress to address contamination associated with the Rocky Flats Plant. These activities are pursuant to the U.S. Department of Energy (DOE) Environmental Restoration (ER) Program [formerly known as the Comprehensive Environmental Assessment and Response Program (CEARP)], a Compliance Agreement between DOE, the U.S. Environmental Protection Agency (EPA), and the State of Colorado Department of Health (CDH) dated July 31, 1986, and a draft Inter-Agency Agreement (IAG) being developed among DOE, EPA, and CDH. The program developed by DOE, EPA, and CDH in response to the agreements addresses Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) issues and has been integrated with the ER Program.

This document has been developed in accordance with Article XI of Attachment 2 of the draft IAG which states that DOE will develop a TSP to evaluate candidate remedial technologies for the general types of contamination encountered at the Rocky Flats Plant. National Environmental Policy Act (NEPA) documentation will be required on this project. Necessary NEPA documentation will be provided in accordance with the IAG schedule. This plan addresses practical treatment technology evaluations for the contaminated media on a sitewide basis. Practical technologies in this TSP have been defined as conventional technologies that have been demonstrated to have potential, or to be viable for full-scale use.

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This document is divided into eight sections and three appendices. Section 1.0 provides an Introduction and background information on the Rocky Flats Plant is presented in Section 2.0. A description of the TSP Objectives is found in Section 3.0 and a description of the Sitewide Contamination is included as Section 4.0. Section 5.0 presents the Technical Approach that will be followed for completing the technology evaluations, as well as the Practical Technologies Summary. Section 6.0, Future Treatability Study Work Plans, provides Statements of Work for each of the proposed treatability studies (Section 6.1), as well as guidelines for the preparation of future treatability study work plans. Section 7.0 presents the deliverables and schedule for completing the program and Section 8.0 lists References used. Appendices include Appendix A - Analyte Concentrations at the major Solid Waste Management Units (SWMU) of Operable Units 1, 2, and 3; Appendix B - Potential Applicable Relevant and Appropriate Requirements (ARARs) for the Sitewide Treatability Studies Program; and Appendix C - Technology Data Sheets.

Table 1-1 lists frequently used Acronyms and Abbreviations. Figure 1-1 shows the primary elements of the Treatability Studies Program; Figure 1-2 shows the timing of the TSP relative to the timing of the individual OU CMS/FSs.

TABLE 1-1 ACRONYMS AND ABBREVIATIONS

AEC	U.S. ATOMIC ENERGY COMMISSION
ARARS	APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS
BDAT	BEST DEMONSTRATED AVAILABLE TECHNOLOGY
CDH	COLORADO DEPARTMENT OF HEALTH
CERCLA	COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980
CMS/FS	CORRECTIVE MEASURES STUDY/FEASIBILITY STUDY
DOE	DEPARTMENT OF ENERGY
DQO	DATA QUALITY OBJECTIVE
EPA	U.S. ENVIRONMENTAL PROTECTION AGENCY
ER	ENVIRONMENTAL RESTORATION
ERDA	ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
FFCA	FEDERAL FACILITIES COMPLIANCE AGREEMENT
FSP	FIELD SAMPLING PLAN
GAC	GRANULAR ACTIVATED CARBON
HSP	HEALTH AND SAFETY PLAN
IAG	INTER-AGENCY AGREEMENT
IHSS	INDIVIDUAL HAZARDOUS SUBSTANCE SITES
NEPA	NATIONAL ENVIRONMENTAL POLICY ACT
NPDES	NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM
OU	OPERABLE UNIT
PCB	POLYCHLORINATED BIPHENYL
QAA	QUALITY ASSURANCE ADDENDUM
QAPP	QUALITY ASSURANCE PROGRAM PLAN
QAPjP	QUALITY ASSURANCE PROJECT PLAN
QA/QC	QUALITY ASSURANCE/QUALITY CONTROL
RCRA	RESOURCE CONSERVATION AND RECOVERY ACT
RFI	RCRA FACILITY INVESTIGATION
RI	REMEDIAL INVESTIGATION
ROD	RECORD OF DECISION
SAP	SAMPLING AND ANALYSIS PLAN
SOP	STANDARD OPERATING PROCEDURE
SWMU	SOLID WASTE MANAGEMENT UNITS
TAR	TECHNOLOGY ASSESSMENT REPORT
TCLP	TOXICITY CHARACTERISTICS LEACHING PROCEDURE
TS	TREATABILITY STUDY
TSP	TREATABILITY STUDIES PLAN
TSDF	TREATMENT, STORAGE, OR DISPOSAL FACILITY
TSR	TREATABILITY STUDIES REPORT

Date: 09/15/90		SITEWIDE/INDIVIDUAL OPERABLE UNIT TREATABILITY STUDIES SCHEDULE											
FIGURE 1-2		Page 1 / 1											
Project Finish: 01/28/99													
Activity Name	Description	Dur	90	91	92	93	94	95	96	97	98	99	
SITWIDE TS	SITWIDE TREATABILITY STUDIES	791											
OU1-FS	OU1 FEASIBILITY STUDY	435											
OU2-TS	OU2-TREATMENT STUDY (MIRA)	61											
OU2-FS	OU2-FEASIBILITY STUDY	417											
OU3	OU3-INFORMATION NOT AVAILABLE	0											
OU4-TS	OU4 TREATMENT STUDY (MIRA)	190											
OU4-FS	OU4 FEASIBILITY STUDY	439											
OU5-FS	OU5 FEASIBILITY STUDY	585											
OU6-FS	OU6 FEASIBILITY STUDY	436											
OU7-TS	OU7-TREATMENT STUDY (MIRA)	191											
OU7-FS	OU7-FEASIBILITY STUDY	436											
OU8-FS	OU8-FEASIBILITY STUDY	441											
OU9-TS	OU9-TREATMENT STUDY (MIRA)	191											
OU9-FS	OU9-FEASIBILITY STUDY	435											
OU10-TS	OU10-TREATMENT STUDY (MIRA)	278											
OU10-FS	OU10-FEASIBILITY STUDY	453											
OU11-TS	OU11-TREATMENT STUDY (MIRA)	196											
OU11-FS	OU11-FEASIBILITY STUDY	435											
OU12-FS	OU12-FEASIBILITY STUDY	442											
OU13-FS	OU13-FEASIBILITY STUDY	223											
OU14-FS	OU14-FEASIBILITY STUDY	443											
OU15	OU15-INFORMATION NOT AVAILABLE	0											
OU16	OU16-INFORMATION NOT AVAILABLE	0											

The Rocky Flats Plant is a government-owned, contractor-operated facility which is part of the nationwide nuclear weapons production complex. The Plant was operated for the U.S. Atomic Energy Commission (AEC) from its inception in 1951 until the AEC was dissolved in January 1975. At that time, responsibility for the Plant was assigned to the Energy Research and Development Administration (ERDA), which was succeeded by the DOE in 1977. Dow Chemical U.S.A., an operating unit of the Dow Chemical Company, was the prime operating contractor of the facility from 1951 until June 30, 1975. Rockwell International was the prime contractor responsible for operating the Rocky Flats Plant from July 1, 1975 until December 31, 1989. EG&G Rocky Flats, Inc. became the prime contractor at the Rocky Flats Plant on January 1, 1990. Additional detail concerning the Plant operations, physical setting, and previous environmental investigations that have been conducted are included in the following subsections.

2.1 PLANT OPERATIONS

The primary mission of the Rocky Flats Plant is to fabricate nuclear weapon components from plutonium, uranium, and nonradioactive metals (principally beryllium and stainless steel). Parts made at the Plant are shipped elsewhere for assembly. In addition, the Plant reprocesses components for recovery of plutonium after they are removed from obsolete weapons.

Both radioactive and nonradioactive wastes are generated in the production process. Current waste handling practices involve on-site and off-site recycling of hazardous materials, on-site storage of hazardous and radioactive mixed wastes, and off-site disposal of solid radioactive materials at another DOE facility. However, both storage

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and disposal of hazardous and radioactive wastes occurred on site in the past. Preliminary assessments under the ER Program identified some of the past on-site storage and disposal locations as potential sources of environmental contamination.

2.2 PHYSICAL SETTING

The Rocky Flats Plant is located in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver (Figure 2-1). The Plant consists of approximately 6,550 acres of Federally owned land in Sections 1 through 4 and 9 through 15 of T2S, R70W, 6th Principal Meridian. Major buildings are located within the Plant security area of approximately 400 acres. The security area is surrounded by a buffer zone of approximately 6,150 acres (Figure 2-2).

The natural environment of the Plant and vicinity is influenced primarily by its proximity to the Front Range of the Rocky Mountains. The Plant is directly east of the north-south trending Rocky Mountains, with an elevation of approximately 6,000 feet above sea level. The Rocky Flats Plant is located on a broad, eastward sloping plain of overlapping alluvial fans developed along the Front Range. The fans extend about five miles in an eastward direction from their origin in the abruptly rising Front Range and terminate on the east at a break in slope to low rolling hills. The Continental Divide is about 16 miles west of the Plant. The operational area at the Plant is located near the eastern edge of the fans on a terrace between stream-cut valleys (North Walnut Creek and Woman Creek).

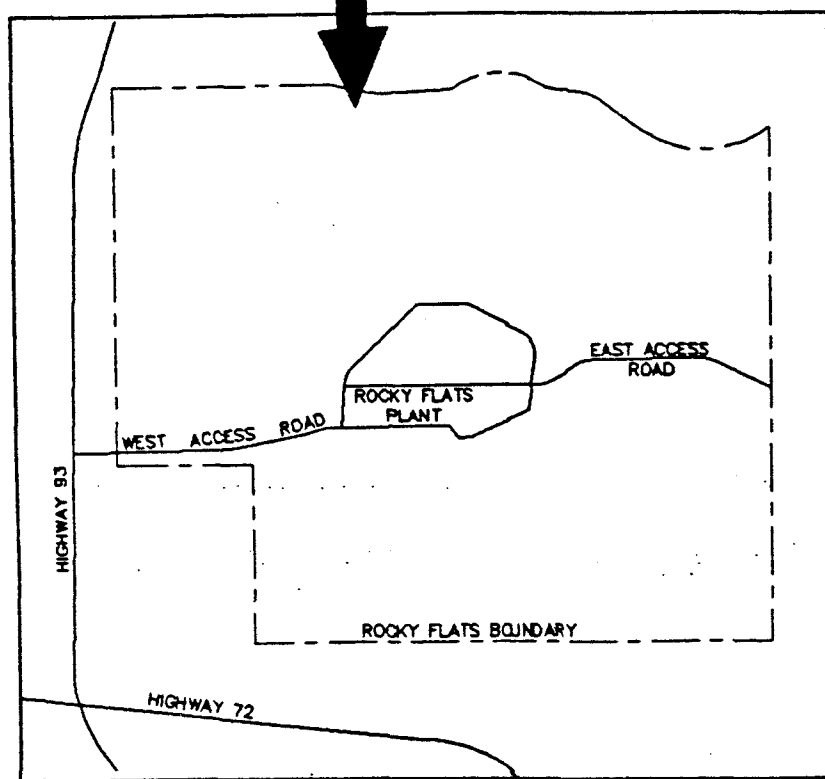
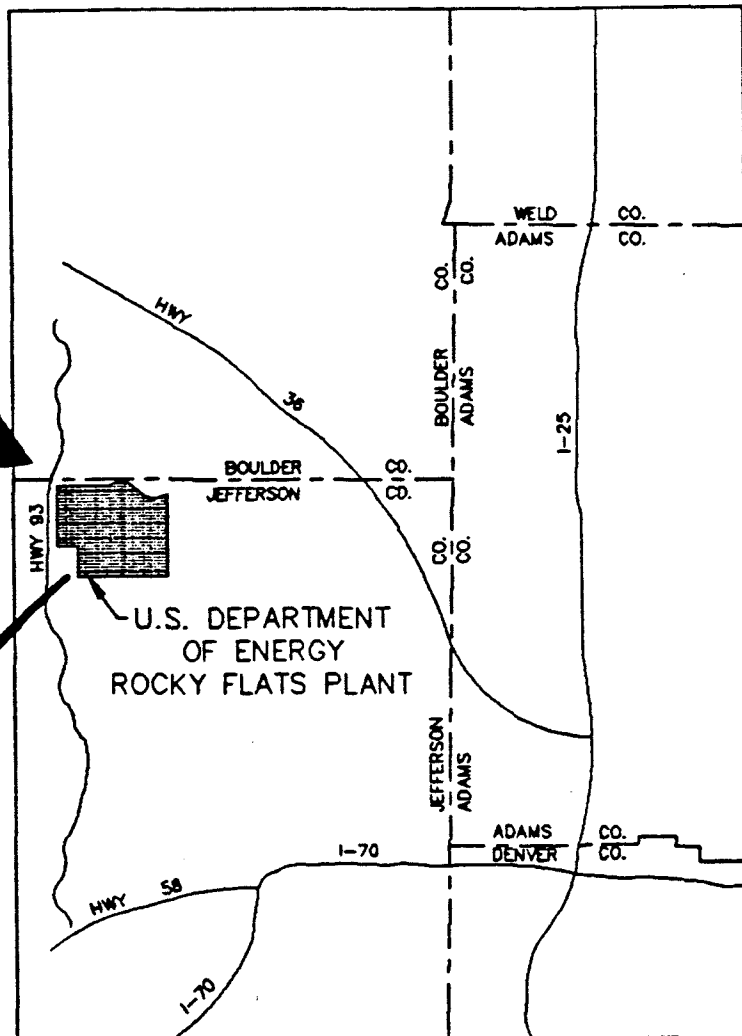
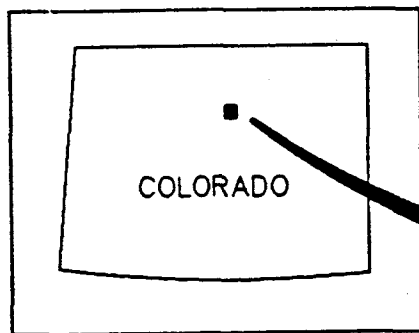
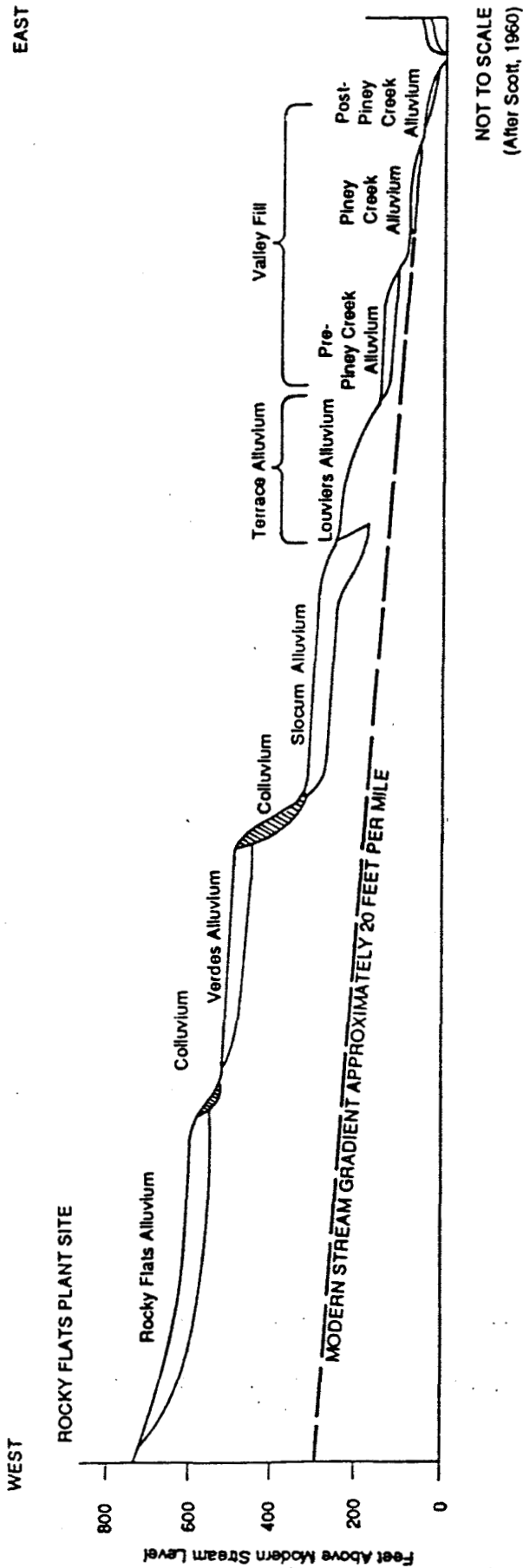


Figure 2-1
LOCATION OF
ROCKY FLATS PLANT

Three intermittent streams drain the Rocky Flats Plant with flow generally from west to east. These drainages are Rock Creek, Walnut Creek, and Woman Creek (Figure 2-2). Rock Creek drains the northwestern corner of the Plant and flows northeast through the buffer zone to its off-site confluence with Coal Creek. An east-west trending topographic divide bisects the Plant separating the Walnut and Woman Creek drainages. North and South Walnut Creeks and an unnamed tributary drain the northern portion of the Plant security area. These three forks of Walnut Creek join in the buffer zone and flow to Great Western Reservoir approximately one mile east of the confluence. Woman Creek drains the southern Rocky Flats Plant buffer zone flowing eastward to Standley Reservoir. The South Interceptor Ditch lies between the Plant and Woman Creek. The South Interceptor Ditch collects runoff from the southern Plant security area and diverts it to Pond C-2, where it is monitored in accordance with the Plant National Pollutant Discharge Elimination System (NPDES) permit prior to discharge to Woman Creek.

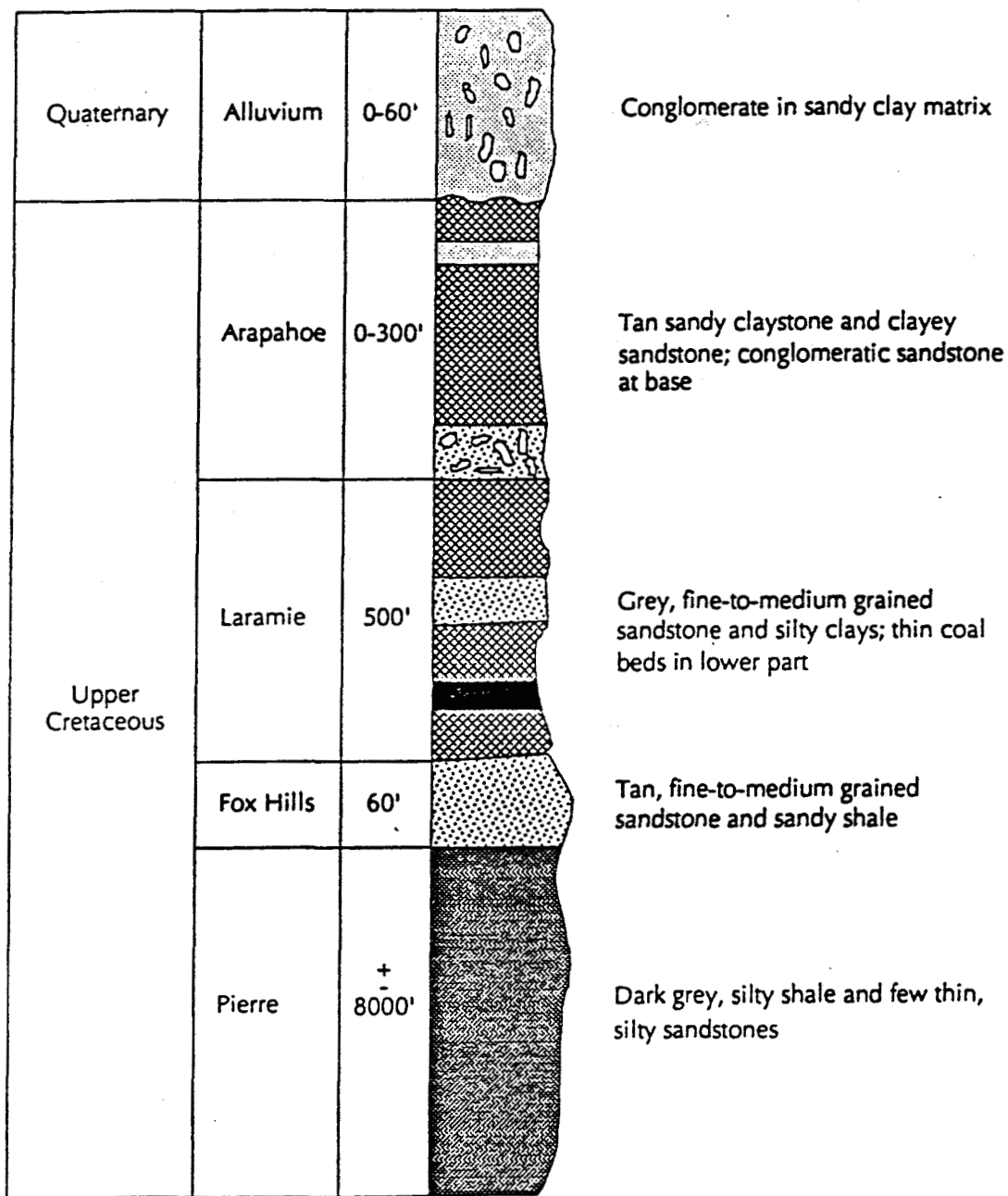
Geologic units at the Rocky Flats Plant (in descending order) consist of the surficial units (Rocky Flats Alluvium, various terrace alluviums, valley fill alluvium, and colluvium) (Figure 2-3) and bedrock (Arapaho Formation, Laramie Formation, and Fox Hills Sandstone) (Figure 2-4). The alluvium is a broad planar deposit consisting of a topsoil layer underlain by up to 100 feet of silt, clay, sand, and gravel. The Arapahoe Formation underlies the surficial deposits, and consists of claystone with thin lenticular sandstones. The Laramie Formation underlies the Arapahoe, and is composed of a thick upper claystone and a lower sandstone. The claystone is greater than 500 feet thick and is of very low hydraulic conductivity; therefore, the U.S. Geological Survey (Hurr, 1976) concluded that Plant operations will not impact any units below the upper claystone unit of the Laramie Formation. Groundwater occurs under unconfined conditions in both the surficial and bedrock units. In addition, confined groundwater flow occurs in bedrock sandstones.



EG86 ROCKY FLATS PLANT

Figure 2-3

EROSIONAL SURFACES AND
ALLUVIAL DEPOSITS EAST OF
THE FRONT RANGE,
COLORADO



EG & G, Rocky Flats Plant

Figure 2-4
GENERALIZED STRATIGRAPHIC
SECTION, ROCKY FLATS AREA

After LeRoy and Weimer, 1971

The area surrounding the Rocky Flats Plant has a semiarid climate characteristic of much of the central Rocky Mountain region. Approximately 40 percent of the 15-inch annual precipitation falls during the spring season, much of it as wet snow. Thunderstorms (June to August) account for an additional 30 percent of the annual precipitation. Autumn and winter are drier seasons, accounting for 19 and 11 percent of the annual precipitation, respectively. Snowfall averages 85 inches per year, falling from October through May (DOE, 1980). Studies of air flow and dispersion characteristics (e.g., Hodgin, 1983 and 1984) indicate that drainage flows (winds coming down off the mountains to the west) turn and move toward the north and northeast along the South Platte River valley and pass to the west and north of Brighton, CO (DOE, 1986).

2.3 PREVIOUS INVESTIGATIONS

Various studies have been conducted at the Rocky Flats facility to characterize environmental media and to assess the extent of radiological and chemical contaminant releases to the environment.

In 1986, two major investigations were completed at the Plant. The first was the ER Program Phase 1 installation assessment (DOE, 1986) which included analyses and identification of current operational activities, active and inactive waste sites, current and past waste management practices, and potential environmental pathways through which contaminants could be transported. A number of sites were identified that could potentially have adverse impacts on the environment. These sites were designated as Solid Waste Management Units (SWMUs) (Rockwell International, 1987) and were divided into three categories:

- Hazardous waste management units that will continue to operate and need a RCRA operating permit

- Hazardous waste management units that will be closed under RCRA interim status
- Inactive waste management units that will be investigated and cleaned up under Section 3004(u) of RCRA or CERCLA. No RCRA or CERCLA regulatory distinction in the use of the terms "site," "unit," or "SWMU" is intended in this document. The IAG (December 1989) designated all SWMUs to be Individual Hazardous Substance Sites (IHSS). These two terms are used interchangeably in this document.

The second major investigation completed at the Plant in 1986 involved a hydrogeologic and hydrochemical characterization of the entire Plant site. Plans for this study were presented in Rockwell International (1986b and 1986c), and study results were reported in Rockwell International (1986d). Investigation results indicated four areas as significant contributors to environmental contamination, with each area containing several sites. The areas are the 881 Hillside Area, the 903 Pad Area, the Mound Area, and the East Trenches Area. Site characterization work has continued since 1986 at several Operable Units (OUs). However, it is not within the scope of this plan to incorporate those results.

The overall objective of the Treatability Studies Program, as presented in this Treatability Studies Plan (TSP), is to provide treatability studies information to support the Corrective Measure Studies or Feasibility Studies (CMS/FSs) that will be conducted at each of the 16 Operable Units (OUs). The program will shorten the overall time required to complete these studies by identifying technologies which are potentially applicable for remediating the types of wastes and waste matrices that may be common to more than one OU. Conducting treatability studies on these technologies as part of the Treatability Studies Program will generate the data required to evaluate and screen technologies and/or alternatives. The program will be implemented separately from the CMS/FSs, and will not replace the extensive identification and screening of technologies that will be conducted by the CMS/FS at each OU. This program may not completely eliminate the need for treatability studies to be conducted during the individual CMS/FSs. The program may reduce the need for these additional treatability studies by 1) eliminating duplicate studies and 2) producing useful database to the CMS/FSs that require the data. Thus, the TSP may expedite the screening of technologies and alternatives for OUs where treatability studies occur later in the sitewide Treatability Studies Program as shown in Figure 1-2. As previously noted, practical technologies are those conventional technologies that have been demonstrated to have potential, or to be viable for full-scale use.

Protocols for conducting treatability studies as part of the Treatability Studies Program or the individual CMS/FSs are required to ensure that the data collected are accurate, complete, and appropriate. The development of these guidelines and any additional requirements is an objective of the program. These guidelines will be used in preparing a Treatability Study Work Plan for each treatability study. Each Treatability Study Work

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Plan will be based on the protocols presented in this document and will provide the test objectives and protocols specific to the technology to be evaluated.

The investigations of the types and extent of contamination at each OU are being conducted under the Environmental Restoration (ER) Program by numerous CERCLA Remedial Investigations (RIs) or RCRA Facility Investigations (RFIs). The data collected by these studies may not provide all the information required to evaluate and screen technologies during the CMS/FSs or to support the conduct of treatability studies. The Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAPjP) for each RFI/RI to be conducted during the duration of the Treatability Studies Program will be reviewed and modified to ensure that appropriate CMS/FSs and treatability study data are collected.

The specific objectives of this program are to:

- Identify, evaluate, and select candidate technologies for treatability testing based on sitewide contamination data
- Provide the protocols for preparing both the Sitewide and Operable Unit Specific Treatability Study Work Plans and for conducting treatability studies
- Review and modify, as required, the FSP and QAPjP to be conducted within the Sitewide Treatability Studies Program
- Prepare the executable level Treatability Study Workplans for the Sitewide Program
- Perform the treatability testing work and provide summary reports along with recommendations.

The technical approach that will be used to meet these objectives is described in Section 5.0.

3.1 RELATIONSHIP OF THE TSP TO OU-SPECIFIC CMS/FSs

The primary purpose of the TSP is to expedite the screening of technologies and alternatives for the types of contaminants that appear to be generally present at the site. In parallel with the TSP will be individual CMS/FSs for each of the 16 OUs at the Rocky Flats Plant. The TSP will provide information to demonstrate whether or not certain technologies should be considered further for specific problems at any of the 16 OUs. However, due to project scheduling constraints (see Figure 1-2), not all of the OU-specific CMS/FSs will benefit from the sitewide TSP; that is, some of the CMS/FS treatability studies will occur before the later of the sitewide treatability studies are complete.

3.2 RELATIONSHIP OF THE TSP TO FFCA REPORTS

The TSP will make maximum use of the work performed by EG&G's Recovery Technology Division which, in compliance with the Federal Facilities Compliance Agreement (FFCA), is developing Technology Assessment Reports (TARs) for waste management technologies. It should be noted that the TARs are oriented toward process waste treatment technology and, as such, may be of some relevance to the treatment of undefined wastes to be remediated under ER programs. The wastes found at the Solid Waste Management Units (SWMUs) are likely to be very different in composition and concentration than the process wastes which are the topic of the TARs.

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Summaries of the potentially hazardous substances found within the groundwater, surface water, soils, and wastes at the Rocky Flats Plant are presented in Section 4.1. This account is not intended to be exhaustive as numerous investigations are currently ongoing or planned for the future, but it does identify the major compounds of concern from a human health and environmental standpoint. Attempts have been made to represent the data from the source documents as accurately as possible. The nine documents which comprise the source of the database used are referenced at the end of this section. The database chosen for use in this report is adequate for the purpose of selecting and screening of the practical technologies that should be considered on a sitewide basis. Section 5.0 provides additional discussion on the available data and its adequacy for the TSP.

For the purpose of developing appropriate remedial actions, the 178 Solid Waste Management Units (SWMUs) at the Rocky Flats Plant were combined into 16 Operable Units (OUs). Specific data on concentrations of contaminants at sites within a given OU are currently only available for OU1, OU2, OU4, OU7, and OU11. A summary of the maximum and minimum analyte concentrations detected in the groundwater, surface water, and soils at these OUs as a group are presented in Table 4-1. This information is presented in detail in Appendix A.

**TABLE 4-1: ANALYTE CONCENTRATIONS
FOR COMBINED OPERABLE UNITS 1, 2, 4, 7, and 11**

PARAMETER	MAXIMUM			MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
INDICATORS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
pH (pH units)	10.6	12.5	NR	5.5	7.3	NR
Silica	NR	NR	NR	NR	ND	NR
Total Dissolved Solids	16776	175800 (1)	NR	118	533	NR
INORGANICS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Bicarbonate as CaCO ₃	682	402	7	23.1	190	NR
Carbonate as CaCO ₃	450	6	NR	<5	<5	NR
Chloride	947	124	37	<2.9	91	12
Cyanide	ND	1.9	0.13	ND	<.0025	0.005
Nitrate as N (2)	2200	1367	1480	<1.5	ND	30
Nitrate+Nitrite as N (2)	55	8	113.7	<0.02	..	46.9
Sulfate	4600	80	744	1.83	8	91
RADIONUCLIDES	pCi/l	pCi/l	pCi/g	pCi/l	pCi/l	pCi/g
Americium 241	0.831	13000	2.2	<0.048	0.12	0.01
Cesium 137	..	..	2.6	<0.78	..	..
Gross Alpha	620	80000	75	<2.0	4	16
Gross Beta	1200	40000	56	<4.0	2	17
Plutonium 239+240	4.7	2100	18	<0.01	0	0.01
Radium 226	NR	NR	NR	NR	NR	NR
Strontium 90 - A	9.3	..	1.9	4	NR	..
Thorium 230+232	NR	0.035	NR	NR	ND	NR
Tritium	20000	6400	0.54	<400	0	0.08
Uranium (total)	62	40000	NR	<1.8	0.69	0.66
Uranium 233+234	40	20000	60	<1.5	0	0.57
Uranium 235	4.3	2.6	NR	..	..	NR
Uranium 238	24	28000	3000	<2.2	0	0.33

(1) This value is for liquid in equilibrium with sludge from the solar ponds

(2) Both analyses not run on all samples; anomaly exists due to combining data from individual data tables in Appendix A.

These are incompatible data sets, comparison is not possible

B = Present in blank

J = Present below quantitation limit

E = Estimated

.. = Value less than tolerance interval or background value as determined in reference documents

< = Below detection limit or background tolerance interval

NR = Not reported, presumably not tested for based on reference documents

ND = Not detected, presumably tested for based on reference documents, but numerical value of detection limit not given

A - Strontium 89, 90 in soils

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**TABLE 4-1: ANALYTE CONCENTRATIONS
FOR COMBINED OPERABLE UNITS 1, 2, 4, 7, and 11 (cont.)**

PARAMETER	MAXIMUM			MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
METALS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Aluminum	36.6	2.64	30899	<0.29	<.0028	9.7
Antimony	0.078	<0.05	21	0.006J	<.028	<41
Arsenic	0.04	0.15	64	0.002J	<.01	0.1
Barium	0.93	0.58	345	0.015	<.071	57
Beryllium	0.26	0.1	103.13	<.005	0.002	0.88
Boron	NR	0.67	NR	NR	0.071	NR
Cadmium	0.018	0.15	345.06	<0.005	<0.01	<3.4
Calcium	826.67	410	72551	6.0019	40	710
Cesium	0.36	0.35	NR	<0.02	0.041	NR
Chromium	0.19	16.7	780	<0.01	0.011	6.8
Cobalt	0.01	0.5	25	<0.02	<0.014	6.9
Copper	0.95	1.8	58	<0.0063	<0.014	6.3
Germanium	NR	ND	NR	NR	<0.014	NR
Iron	28.2	8	30300	<0.0069	<0.03	9160
Lead	0.054	ND	63	<0.01	<0.0028	7.9
Lithium	0.7	6	NR	0.01J	0.052	NR
Magnesium	291.73	120	6730	<5.46	21	250
Manganese	4.23	0.42	1258	0.0051	<0.0028	200
Mercury	0.9	0.5	1490	0.0001J	ND	0.18
Molybdenum	0.51	<0.1	11	<0.022	<0.0028	<8.8
Nickel	1.4	2	543	<0.037	<0.03	12
Niobium	NR	<0.18	NR	NR	<0.14	NR
Potassium	260	14300	5200	<0.5	9	120
Rubidium	NR	0.35	NR	NR	<0.028	NR
Selenium	3.2	0.024	0.5	0.002J	<0.005	<0.01
Silver	0.13	0.082	2.2	<0.0003	<0.0028	<0.88
Sodium	4447	42900	2230	6.97	67	68
Strontium	9.47	3.5	209	<0.01	0.14	14
Tantalum	NR	<0.035	7.6	NR	<0.028	NR
Tellurium	NR	ND	NR	NR	<0.28	NR
Thallium	0.019	<0.01	90	<0.01	<0.014	<1.1
Tin	ND	13	..	<0.1	<0.028	<41
Titanium	NR	<0.018	NR	NR	<0.014	NR
Tungsten	NR	<1.8	NR	NR	<1.4	NR
Vanadium	0.85	0.2	80	<0.014	<0.014	NR
Zinc	2.77	0.05	116	<0.02	0.041	24
Zirconium	NR	<0.035	NR	NR	0.0041	NR

B = Present in blank

J = Present below quantitation limit

E = Estimated

.. = Value less than tolerance interval or background value as determined in reference documents

< = Below detection limit or background tolerance interval

NR = Not reported, presumably not tested for based on reference documents

ND = Not detected, presumably tested for based on reference documents, but numerical value of detection limit not given

**TABLE 4-1: ANALYTE CONCENTRATIONS
FOR COMBINED OPERABLE UNITS 1, 2, 4, 7, and 11 (cont.)**

PARAMETER	MAXIMUM			MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
SEMI-VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
Benzo(a)Anthracene	ND	NR	400	ND	NR	<390
Benzo(a)pyrene	ND	NR	520	ND	NR	<390
Benzo(b)fluoranthene	ND	NR	560	ND	NR	<390
Benzo(g,h,i)perylene	ND	NR	880	ND	NR	<390
Benzo(k)fluoranthene	ND	NR	680	ND	NR	<390
Fluoranthene	ND	NR	1600	ND	NR	<390
Indeno(1,2,3-cd)pyrene	ND	NR	560	ND	NR	<390
Phenanthrene	ND	NR	1400	ND	NR	<390
Phenols	ND	0.046	0.5	ND	0.003	ND
Pyrene	ND	NR	1300	ND	NR	<390
VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
1,1-Dichloroethane	180	ND	ND	<5	<5	ND
1,1-Dichloroethylene	7900	ND	ND	<5	<5	ND
1,1,1-Trichloroethane	15000	ND	250	29	<5	ND
1,1,2-Trichloroethane	47	ND	2J	<5	<5	ND
1,1,2,2-Tetrachloroethane	5	ND	ND	<5	<5	ND
1,2-Dichloroethane	17	ND	32	<5	<5	ND
2-Butanone	ND	ND	19	<10	<10	<10
Acetone	19B	2	1100	<10	<10	14B
Carbon Disulfide	3J	ND	58	<5	<5	ND
Carbon Tetrachloride	2400J	ND	100	<5	<5	ND
Chloroform	330	1	ND	<5	<5	ND
Chloromethane	ND	ND	70B	<10	<10	ND
Dichloromethane	83	35B	90	8	<5	29B
Methyl Ketone	15	3.5	61	ND	ND	1J
Tetrachloroethene	45000	8	10000	<5	<5	ND
Toluene	0.19	2	43	<5	<5	ND
Trichloroethene	49000	ND	16000	4	<5	ND
Vinyl Chloride	520	ND	ND	<10	<10	ND

B = Present in blank

J = Present below quantitation limit

E = Estimated

.. = Value less than tolerance interval or background value as determined in reference documents

< = Below detection limit or background tolerance interval

NR = Not reported, presumably not tested for based on reference documents

ND = Not detected, presumably tested for based on reference documents, but numerical value of detection limit not given

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4.1 SUMMARY OF CONTAMINANTS - GENERAL

A summary of the contaminants detected in each matrix, e.g., groundwater, surface water and soils, is presented below.

Groundwater

During 1986, groundwater samples were analyzed for the Target Compound List (TCL) volatiles and semivolatiles, and for the Target Analyte List (TAL) metals as well as major ions and radionuclides. During subsequent years, testing was limited to those contaminants previously detected. Elevated levels (e.g., above background as referenced in the data source documents) of inorganics, metals, volatile organics, and radionuclides have been detected at various sites within a given Operable Unit (OU).

At OUs 1, 4 and 11, there are high concentrations of nitrates or nitrates + nitrites (>55 mg/l) and high concentrations of chlorides (>275 mg/l). Sulfates are present in high concentrations in OU1 and OU2. Metals of concern (e.g., above potential Applicable or Relevant and Appropriate Requirements (ARARs) listed in Appendix B) in groundwater include mercury, chromium, selenium, nickel, iron, and manganese in OU1; mercury, chromium, selenium, nickel, iron, manganese, copper, silver, vanadium, and zinc in OU2; manganese, molybdenum, nickel, and selenium in OU4; chromium, selenium, nickel, iron, manganese, molybdenum, aluminum, lead, and beryllium in OU7; and chromium, iron, manganese, mercury, and molybdenum in OU11. No semivolatile organics have been reported as detectable in groundwater in these OUs. Volatile organic compounds (VOCs) of concern (e.g., above ARARs) include carbon tetrachloride (OUs 1 and 2), 1,1-dichloroethylene (OU1), 1,1,1-trichloroethane (OU1), 1,2-dichloroethane (OU1), tetrachloroethene (OUs 1 and 2), trichloroethene (OUs 1 and 2), chloroform (OU2) and vinyl chloride (OU2). Elevated levels (i.e., above background as defined in Rockwell International, 1989) of americium 241, plutonium 239 + 240, and

strontium 90 were detected in the groundwater of OUs 1, 2, and 7. Elevated levels of tritium and uranium 233 + 234 were detected in OUs 1, 7 and 11, and both uranium 235 and uranium 238 were detected in OU1. Elevated levels of plutonium 239 + 240 and uranium 235 were detected in OU11. Total uranium is high in OU2. The highest concentrations of uranium 233 + 234 in OU7 and OU11 occurred in 1986 and may be nonrepresentative outliers.

Surface Water

Elevated levels (i.e., above background) of inorganics, metals, volatile organics, semivolatile organics, and radionuclides have been detected. OU4 surface water may contain levels above ARARs of cyanide, the metals, chromium, selenium, nickel, arsenic, cadmium, copper, iron, and manganese, as well as elevated levels of lithium and the semivolatile phenol. Both OU7 and OU11 contain manganese at levels above ARARs and OU11 contains the inorganic nitrate and the metals copper, iron, and mercury at levels of concern. In addition, the surface waters of OU4 contain americium 241, plutonium 239 + 240, uranium 233 + 234, uranium 238, and tritium above background levels. The surface water of OU7 contain elevated levels of americium 241, uranium 235, and uranium 238, and OU11 contains elevated levels of tritium. The surface waters of OU1 may contain levels of chromium above ARARs. Uranium 233 + 234, uranium 235, and uranium 238 were present at levels above background in OU1. Interim measures at OU2 will be performed for surface water.

Soils

Elevated levels of inorganics, metals, volatile organics, semivolatile organics, and radionuclides have been detected in some of the OUs. Nitrate is elevated in the soils within OU4 and OU11. Elevated concentrations of cadmium, iron, and aluminum have been detected in soils in OU4, iron and mercury in OU7, and mercury in OU11 soils.

In addition, OU7 contains elevated concentrations of several semivolatiles including fluoranthene, phenanthrene, and pyrene. The detected Volatile Organic Compounds (VOCs) include tetrachloroethene, 1,1,1-trichloroethane, and trichloroethene in soils of OUs 1 and 2. In addition, cesium 137, plutonium 239 + 240, strontium 89 + 90, tritium, uranium 233 + 234, and uranium 238 may be above background at OU1. Plutonium 239 + 240 and americium 241 are elevated at OU4, OU7, and OU11. In addition, elevated levels of uranium 238 were detected in OU4 and elevated levels of tritium in OU11.

4.2 SUMMARY OF CONTAMINANTS - OPERABLE UNITS

A brief description of each OU and the contamination problems contained within these OUs are presented below.

Operable Unit 1 - 881 Hillside

The 881 Hillside area is located in the southeast corner of the Rocky Flats Plant and consists of 11 hazardous substance sites. These hazardous substance sites may have contaminated the alluvial groundwater and, in some cases, the soil with VOCs. VOCs that have been found to be present at significant concentrations (e.g. above ARARs) in the alluvial groundwater are:

- 1,1-Dichloroethylene
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- 1,2-Dichloroethane
- Carbon Tetrachloride
- Tetrachlorethene
- Trichloroethene

The concentrations of nitrate or nitrite, chloride, and sulfate may be present above ARARs in groundwater. Several radionuclides have been detected at elevated concentrations including uranium 235 and 238, uranium 233 + 234, americium 241, plutonium 239 + 240, strontium 90, tritium, and gross alpha and gross beta decay. Metals of concern (e.g. above ARARs) include mercury, chromium, selenium, nickel, manganese, and iron.

Elevated chromium concentrations have been reported for surface waters. Uranium 233 + 234, uranium 235, uranium 238, and radium 226 have been reported at elevated concentrations in surface waters.

Soils in OU1 contain elevated levels of cesium 137, plutonium 239 + 240, Strontium 89 + 90, tritium, uranium 233+234, and uranium 238. High levels of the metals chromium and iron have been reported. Semivolatiles have not been detected in the soils but elevated levels of the volatiles 1,1,1-trichloroethane, tetrachloroethene, and trichloroethene have been found in the soil.

Wastes spilled or disposed of within OU1 hazardous substance sites are: asbestos, fuel oil, waste oil, solvents, scrap metal, empty drums, and plutonium-contaminated soil and asphalt.

Operable Unit 2 - 903 Pad, Mound Area, and East Trenches

OU2 consists of 20 hazardous substance sites including the 903 Pad, Mound Area, and East Trenches. The 903 Pad is located in the southeast corner of the Rocky Flats Plant adjacent to 881 Hillside. The Mound Area is north of Central Avenue and west of the East Guard Gate, and the East Trenches are east of the 903 Pad. Other hazardous substance sites are located in the vicinity of the 903 Pad and Mound Area.

Hazardous substance sites in OU2 have contaminated the groundwater with inorganic compounds, VOCs, and radionuclides. No inorganics other than chloride (>275 mg/l) and sulfate (>250 mg/l) have been detected at levels of concern in OU2 groundwater. VOCs detected at significant concentrations are carbon tetrachloride, tetrachloroethene, trichloroethene, chloroform, and vinyl chloride. Elevated levels of gross alpha, gross beta, americium 249, plutonium 239 + 240, strontium 90, and total uranium are present in the groundwater. Mercury, chromium, iron, nickel, selenium, copper, manganese, silver, vanadium, and zinc were identified as metals of concern.

The VOCs, tetrachloroethene, trichloroethene, and 1,1,1-trichloroethane have been detected at high concentrations in soils.

Wastes that were disposed of in OU2 include depleted uranium, plutonium chips, lathe coolant, uranium and plutonium-contaminated sewage sludge, asphalt, drums, and metal chips. Several of these disposal sites have been remediated. Solvents and other chemicals were also disposed of, or spilled, in this area.

Operable Unit 3 - Off-Site Units

OU3 consists of four hazardous substance sites which are off-site (generally lying east of Indiana Street and adjacent to RFP) or could impact off-site areas. These sites include: land surface, Great Western Reservoir, Standley Reservoir, and Mower Reservoir. These sites are currently under investigation as part of the Rocky Flats Plant agreements with EPA and CDH. Radiochemical components may be of concern in the surface water and soil. Radionuclide analysis of Great Western Reservoir and Standley Reservoir indicate that low levels of various radionuclides are present in the surface water.

Operable Units 4, 7, 9, 10, 11, and 15 - RCRA Closure Units

The RCRA closure units consist of 32 hazardous substance sites including the 207-Solar Ponds, the Present Landfill, Original Process Waste Line, Other Outside Closures, West Spray Field, and Inside Building Closures.

Plutonium 239 + 240, tritium, americium 241, strontium 90, and uranium 233 + 234 were the only radionuclides found at high activities in groundwater, although gross alpha and beta activities were also high (620 and 1,200 pCi/l, respectively). Metals of concern identified in groundwater were mercury, chromium, iron, nickel, selenium, manganese, beryllium, molybdenum, aluminum, and lead. Nitrates and chlorides were reported above ARARs in groundwater. No significant levels of semivolatile organic compounds were found in groundwater.

Radionuclides which appear to exist above background levels in surface water include americium 241, plutonium 239+240, tritium, uranium 233+234, uranium 235, and uranium 238. The gross alpha and beta activities were measured at 80,000 and 40,000 pCi/l, respectively. Cyanide and nitrate were the major inorganics of concern. Metals reported at high concentrations were chromium, mercury, cadmium, nickel, copper, manganese, selenium, arsenic, and iron. Low concentrations of phenols were detected.

Soils contained elevated levels of the radionuclides americium 241, uranium 238, tritium, and plutonium 239+240. The inorganics detected at elevated levels were cyanide, chloride, and nitrate. Metals found at elevated levels were cadmium, iron, aluminum, thallium, and mercury, as well as several other metals to a lesser extent. All semivolatiles analyzed except phenols were found at elevated contamination levels. The only VOCs of concern that were found were low levels of tetrachloroethene and dichloromethane.

Wastes associated with the hazardous substance sites include sanitary sewage sludge, various metals, and organic solvents. The present landfill contains various solid wastes generated at the Rocky Flats Plant. The following items were registered as deposited in the present landfill and may represent hazardous waste threats:

- Rags with freon and trichloroethene
- Liquid chemical containers
- Metal chips
- Paper towels with oil and freon
- Empty paint cans
- Organic chemicals in cabinet
- Mercury vapor lamp bulbs
- Deionizer exchange resin column
- Copy machine toner
- Dispersant containers
- Demineralizer system filters
- Empty ink cans
- Empty solvent containers
- Empty chemical containers
- Settling basin sludge
- Oil filters
- Mineral and asbestos dust
- Fire extinguisher chemicals
- Paint filters
- Steel shavings and scraps
- Sump sludge
- Photography lab solid wastes
- Aerosol, paint, and thinner cans
- Fiberglass resins and catalysts.

Operable Units 5 and 6 - Woman Creek and Walnut Creek Drainages

OU5 and OU6 consist of 30 hazardous waste sites throughout the Rocky Flats Plant. The majority of these sites are surface retention ponds associated with North Walnut Creek, South Walnut Creek, and Woman Creek. Other hazardous waste sites include trenches, outfalls, and spray fields. Comprehensive chemical analysis of groundwater, surface water, and soil has not been completed. However, some sitewide data are available.

OU5 and OU6 surface water contain americium, plutonium, uranium, and tritium in relatively low concentrations. Surface water contains unspecified concentrations of metals, nitric acid, plutonium, uranium, and unspecified wastes and radiochemical components. Soils have been subject to spills consisting of acids, metals, nitric acid, fuel oil, organics, sanitary sewer sludge, sodium, solvents, sulfates, and unspecified wastes and radiochemical components.

Operable Unit 8 - 700 Area

OU8 consists of 38 hazardous waste sites throughout the Rocky Flats Plant. Many of the sites are associated with storage tanks while the remainder are leaks or spills. Wastes at these sites are associated with soils. However, chemical analysis of groundwater and surface water are not yet available. Various substances have leaked onto the soil in this OU and include: acids, algicides, bases, beryllium, carbon tetrachloride, chromates, caustics, fluorides, hydrocarbons, metals, nitrates, organics, solvents, and unspecified wastes and radiochemical constituents.

Operable Unit 12 - 400/800 Area

OU12 consists of 12 hazardous waste sites in the southeast portion of the Rocky Flats Plant. Several of the sites are surface ponds; however, the majority are leaks or spills. Chemical analysis of groundwater, surface water, and soils are not yet available for this OU. Waste that spilled or leaked onto the soil include: acids, algicides, chromates, resins, catalysts, and solvents.

Operable Unit 13 - 100 Area

OU13 consists of 15 sites in the eastern sections of the Rocky Flats Plant. These sites are spills, leaks, waste destruction sites, and storage areas. Chemical data are not available for this OU. Historical data indicate that acids, bases, oil, organics, soaps, solvents, radiochemical components, as well as hydrogen peroxide and sodium hydroxide have spilled onto the soil in this OU.

Operable Unit 14 - Radioactive Sites

OU14 consists of nine hazardous substance sites which are located throughout the Rocky Flats Plant. Data on waste types indicate that unspecified radiochemical components, plutonium, and VOCs have been spilled on or buried in the soils within this OU.

Operable Unit 16 - Low Priority Sites

OU16 consists of seven low priority hazardous substance sites throughout the Rocky Flats Plant which are spill, leak, and disposal areas. Relatively few waste components are associated with the soils in this OU. Reported wastes are: 1,1,1-trichloroethane, antifreeze, nickel carbonyl, and oil.

DATABASE SOURCE DOCUMENTS

DOE. 1990a, January.

DOE. 1990b, January.

EG&G Rocky Flats. 1990, March 30.

Rockwell International. 1988a, July 1.

Rockwell International. 1988b, July 1.

Rockwell International. 1988c.

Rockwell International. 1988d, October 5.

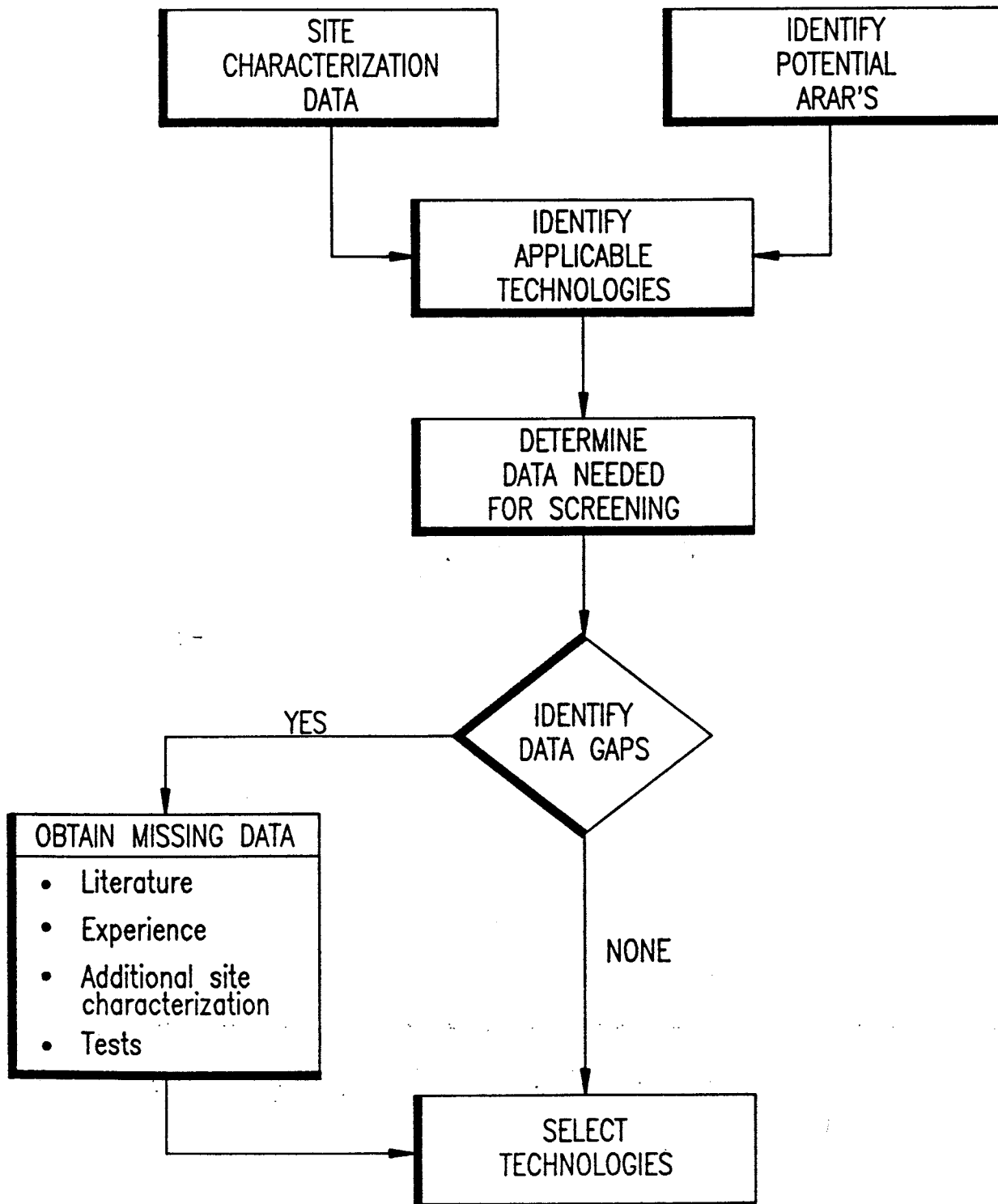
Rockwell International. 1989a, November.

Rockwell International. 1989b, December 15.

The Treatability Studies Program has been designed to identify and evaluate technologies that are broadly applicable for remediating the types of waste and contaminated media that exist at the Rocky Flats Plant. This program is displayed in Figure 1-1. The elements of the program are the Treatability Studies Plan, Practical Technologies Summary, Innovative/Emerging Technologies Assessment Report, and Treatability Study Work Plans (including the Treatability Study Reports). This section on the Technical Approach includes the Treatability Studies Plan, Section 5.1, and the Practical Technologies Summary, Section 5.2.

The overall technology selection and screening process used for the TSP is shown in Figure 5-1. Based on site characterization data and anticipated potential Applicable or Relevant and Appropriate Requirements (ARARs), the potentially applicable technologies are identified. Once this has been accomplished, the data required for screening these technologies will be determined. By comparing the available site characterization data with the data required, the data gaps will be identified. As appropriate, the missing data will then be obtained via literature search, personal experience, additional site characterization and/or additional testing. Once the data gaps have been filled, the screening process will be completed and the appropriate technologies will be selected.

FIGURE 5-1 TECHNOLOGY SELECTION AND SCREENING PROCESS



Screening of practical technologies for laboratory and bench-scale testing is primarily a process of eliminating technologies that are:

- Inappropriate for the application
- Appropriate, but already well proven for similar applications
- Appropriate, but not amenable for lab or bench testing, and can only be pilot tested (e.g., vacuum extraction).

For the practical technologies, it is not necessary that the site characterization data and ARARs be fully developed since the treatability studies are intended to confirm general feasibility of the selected technologies. For instance, it should be noted that data for volatiles are shown in many instances as ND or NR in Tables A-1 through A-3, although other databases have shown them to be present. For the purpose of the sitewide Treatability Studies Program, it has been assumed (in accordance with the larger database) that they are present. For the innovative/emerging technologies, a more complete database will be available, and a better definition of ARARs may also be available.

The first step in evaluating technologies is the identification of potentially applicable technologies for remediation of the general types of wastes and waste matrices that occur at the Rocky Flats Plant. These include organic chemical-contaminated wastes in soil, surface water, and groundwater; metals-contaminated wastes in soil, surface water, and groundwater; and radionuclide-contaminated wastes in soil, surface water, and groundwater. The screening of candidate technologies for inclusion in the Treatability Studies Program will be based on contamination data from all the OUs, not any one specific OU. However, if a unique situation is identified during the program that will

require treatability studies during the CMS/FS for a specific OU, these studies could potentially be included into the Program.

The technology evaluations will be completed in a manner to ensure that a comprehensive evaluation of potentially applicable treatment technologies is provided. To achieve this, the technologies will be grouped into two categories: practical and innovative/emerging. Practical technologies have been defined as conventional technologies that have been demonstrated to have potential, or to be viable for full-scale use. This would include technologies that are being considered for treating a specified type of contamination and medium (e.g., air stripping for volatile organics in water) at the Rocky Flats Plant site. Innovative/emerging technologies have been defined as all other technologies that could potentially be effective but have not been adequately demonstrated to be effective on a full-scale production basis (e.g., *in situ* soil flushing for volatile organics in soils). The evaluation of the practical technology category will be initiated first. Then, although not specifically requested in the IAG, the evaluation of the innovative/emerging category will be initiated on a predetermined schedule to provide an early evaluation of promising new technologies.

The program's first objective is to develop treatability studies that provide the requisite data to screen technologies and develop remedial alternatives. The second objective is to provide more detailed data necessary to perform a detailed evaluation of remedial alternatives. The results obtained from the treatability studies may provide important information for the planning of some OU-specific treatability studies programs. This will be accomplished by providing data that demonstrate whether or not a given technology is effective and should be considered further.

A Treatability Study Work Plan will be developed to provide the procedures and protocols used in conducting each required treatability study. These procedures for conducting treatability studies will be available for use by the individual CMS/FSs and

will help to ensure consistency and completeness of data collection. It should be noted that the sitewide Treatability Study Program will be initiated prior to the individual OU CMS/FSs. However, due to scheduling constraints, not all OU CMS/FSs will benefit from the results of the sitewide program, as some CMS/FS treatability studies will be initiated prior to completion of the later sitewide treatability studies.

5.1 PRACTICAL TECHNOLOGY SELECTION PROCESS

The technology selection process as presented herein has consisted of identifying, screening, and evaluating primary treatment technologies for inclusion in the Treatability Studies Program that will be broadly applicable on a sitewide basis. Preliminary site characterization data and available potential ARARs will be used to identify the major waste categories and associated media that exist at the Rocky Flats Plant (e.g., volatile organics in soil). The applicable treatment technologies will then be determined for each major waste category and associated medium. The resulting list of treatment technologies will be screened to select candidate technologies for the purpose of conducting treatability studies. Using available information, each technology will be evaluated on its effectiveness and implementation. Data gaps will be identified. In conclusion, a technology assessment report will be written to document the process.

The following subsections describe the procedures that will be followed to complete the technology selection process. Subsection 5.1.1 describes the procedure for the evaluation of the available data. Subsection 5.1.2 describes the procedure that will be followed to identify ARARs. Subsection 5.1.3 describes the technology evaluation procedure; and Subsection 5.1.4 describes the procedure for determining what type of treatability study will be conducted. Subsection 5.1.5 describes the resulting Technology Summary.

5.1.1 Data Compilation

Data compilation will be required to determine the types and concentrations of contaminants at the Rocky Flats Plant site. The appropriate data will be derived from the following documents:

- Phase III RI/FS Work Plan, Rocky Flats Plant, 881 Hillside Area, Operable Unit No. 1 (DOE, 1990c)
- Interim Measures/Interim Remedial Action Plan and Decision Document, 881 Hillside Area, Operable Unit No. 1 (DOE, 1990b)
- Environmental Assessment for 881 Hillside (High Priority Sites) Interim Remedial Action (DOE, 1990a)
- Proposed Interim Measures/Interim Remedial Action Plan and Decision Document, 903 Pad, Mound, and East Trenches Area, Operable Unit 2, Medium Priority Site (Rockwell International, 1989)
- RCRA Post Closure Care Permit Application (Rockwell International, 1988d)
- Rocky Flats Plant Site Environmental Report (Rockwell International, 1988c)
- Present Landfill Closure Plan (Rockwell International, 1988b)
- Solar Evaporation Ponds Closure Plan (Rockwell International, 1988a)
- (Draft) Feasibility Study Report for High Priority Site (881 Hillside Area) (Rockwell International, 1988)

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- RCRA Post Closure Care Permit Application (Rockwell International, 1986d).

To facilitate identification of potentially applicable technologies, maximum and minimum concentrations of chemical parameters analyzed for groundwater, surface water, and soils for each OU will be summarized where possible. Remedial Investigations (RIs) of OUs 1 and 2 have been or are currently in progress and these data are available. Data above background will be reported and compared to potential ARARs when available. Background for radionuclides will be previously identified Rocky Flats Plant background concentrations (Rockwell International, 1989). Minimum values are not reported for many analytes in OU1 data; therefore, the assumed minimum values will be previously identified Rocky Flats Plant background concentrations (DOE, 1990c). Maximum and minimum values have been reported for OU2. Site characterization data are not available for the other OUs at this time. However, a limited number of analyses are available from closure plans for the Present Landfill, Solar Ponds, and West Spray Fields. In these plans, maximum and minimum values are reported. All other data are derived from narratives of individual hazardous substance sites (IHSS). These data are qualitative and are reported as such.

When available, the computerized database will be used to identify the predominant contaminants for each environmental medium on a sitewide basis.

5.1.2 ARAR Identification

ARARs are required to provide a basis for determination of potential contaminants of concern and to evaluate the effectiveness of a technology. Potential ARARs will be identified in accordance with Section 121(d) of CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. Of the three categories of ARARs, chemical-specific ARARs are the most appropriate in evaluating the effectiveness of a technology and the results of a treatability study. Since the purpose

of the treatability studies is to evaluate a technology's effectiveness at treating waste at the Rocky Flats Plant site, and the location- and action-specific ARARs provide little information on how effectively technology treats waste, they will not be considered at this time. Action-and location-specific ARARs will be evaluated prior to full-scale implementation of a remedial alternative.

Potential chemical-specific ARARs identified for use by this practical technologies program for water are presented in Appendix B. They will be considered preliminary and subject to change as new Federal and state standards are imposed, and as additional information from the risk assessments and site characterization investigations for each OU are available. Potential chemical-specific ARARs for contaminated soil would include the RCRA Land Disposal Restrictions in 40 CFR 268 and the RCRA Toxicity Characteristic Leaching Procedure (TCLP) in 40 CFR 261. It is expected that a better definition of ARARs will be available for the selection and screening of the innovative/emerging technologies. LDRs and TCLP regulatory levels would also potentially be ARARs when sludges from treated surface and groundwater are removed off-site for disposal. The final ARARs determination for each OU will be completed as part of the CMS/FS conducted for that specific OU.

5.1.3 Treatment Technology Evaluation

The treatment technology evaluation consists of associating the applicable technologies with the major waste categories, and then screening the list to select the candidate technologies. The major waste categories have been identified for each medium based on the available sitewide contamination data and potential ARARs. The potential ARARs were compared to the available chemical concentration data to identify the contaminants of concern. The identified contaminants of concern have then been

grouped into major categories for both the soil and water media (e.g., volatile organics, semivolatile organics, metals, radionuclides, and inorganics). When additional data are available, this procedure will be repeated to determine if additional categories or contaminants of concern need to be added or existing categories deleted.

Potentially applicable treatment technologies have been identified for each major waste category and contaminated medium matrix. They have been identified by drawing on a variety of sources including references developed for application to Superfund sites, RCRA Best Demonstrated Available Technology (BDAT) studies, standard engineering text books, numerous technology databases, DOE studies, and other project experience. Technology data sheets (Appendix C) have been prepared for each identified technology and include a process description, applicability, and the advantages/disadvantages of the technology.

From the list of candidate treatment technologies, the technologies have been screened to identify those that will require treatability testing. In this step, the list of potentially applicable treatment technologies has been reduced by evaluating the information available with respect to technical implementability and effectiveness. Consideration has been given to the current state of development of each technology. For example, whether or not the technology has been commercialized or demonstrated as effective via extensive research and development will be an important factor in the screening process. The effectiveness evaluation has considered each technology's ability to provide protection consistent with the potential ARARs and achieve reductions in toxicity, mobility, or volume of the waste. The implementability evaluation has considered the ability of each technology to be constructed and to be reliably operated. For the purpose of screening, the implementability and effectiveness of a technology has been considered in general terms based on available information. Final decisions regarding a technology's implementability or effectiveness will be made during the individual OU CMS/FS. In addition, treatment technologies have been screened from the list if they

have been demonstrated (by the literature or by prior experience) to be effective for the anticipated Rocky Flats Plant-specific conditions and, therefore, do not require detailed evaluations to determine their applicability and effectiveness. For example, air stripping of volatile organics has been adequately demonstrated to be effective and therefore, a treatability test would not be required. Treatment technologies have also been screened from the list if their value is primarily for pretreatment or residuals management.

5.1.4 Determination of Type of Treatability Study

Laboratory screening and/or bench-scale testing treatability testing will be conducted on each of the selected technologies. The term "laboratory screening" refers to tests that will be limited in size and scope such as small-scale jar tests or beaker studies and that are performed on the bench-top. This type of screening will yield primarily qualitative data to be used as indicators of a technology's potential to meet performance goals.

The term "bench-scale" testing refers to bench-top separation, reaction, or other treatment steps that are performed in the laboratory or field with equipment designed to simulate the basic operation of a treatment process. The data from this type of testing will be used to verify that the technology can meet anticipated cleanup goals, and to provide relative cost and limited design information. Bench-scale tests will also provide information needed to size unit operations and to estimate treatment train considerations such as waste mixing, materials handling, and residuals treatment.

The term "pilot-scale" testing refers to the use of pilot-plant or field-testing equipment with a configuration similar to that of the full-scale operating unit being considered (e.g., mobile pilot-scale unit operation). Information obtained from the laboratory screening and bench-scale testing would be used for future pilot-scale testing of Innovative/Emerging Technologies.

Table 5-1 provides a general comparison of the types of treatability testing tiers including the type of data generated; the analytical level used; the number of critical parameters investigated; the number of replicates required; the study size, usual process type, and waste volume needed; and the typical duration and cost of conducting a study.

For the treatability studies described later, both laboratory testing and bench-scale testing have similar objectives. The primary differences pertain to the quantity of material used for testing and the type of equipment required.

The determination of the level of testing will be made by assessing the technologies under consideration, performance goals, and site characteristics. The choice will be affected by the level of development of the technology in direct application to the contaminants and waste/media at the Rocky Flats Plant. If the technology's validity has not been confirmed, a laboratory screening may be performed. If more quantitative performance data are required, the laboratory screening tier may be bypassed in favor of bench-scale testing. For technologies that are well developed and tested, bench studies are often sufficient to evaluate effectiveness on new wastes.

For example, biological treatment is a technology that has been demonstrated to be effective in the biodegradation of various aqueous wastes, but for which laboratory scale

TABLE 5-1. GENERAL COMPARISON OF LABORATORY SCREENING, BENCH-SCALE TESTING, AND PILOT-SCALE TESTING

Tier	Type of Data Generated	Analytical Level*	Critical Parameters	Number of Replicates	Study Size	Usual Process Type	Waste Stream Volume	Time Required	Cost, \$
Laboratory screening	Qualitative	I-II	Several	Single/duplicate studies	Jar tests or beaker	Batch	Small	Hours/days	10,000-50,000
Bench-scale testing	Quantitative	III-V	Few	Duplicate/triplicate	Bench-top (some larger)	Batch or continuous	Medium	Days/weeks	50,000-250,000
Pilot-scale testing	Quantitative	III-V	Few	Triplicate/ or more	Pilot-plant (on-site or off-site)	Batch or continuous	Large	Weeks/months	250,000-1,000,000

* Analytical levels are defined in Data Quality Objectives for Remedial Response Activities (EPA, 1987a); see Subsection 6.2.3.

studies are normally required because of the technology's dependence on waste-specific composition and concentration levels. An example of a technology for which both laboratory and bench-scale studies would be bypassed is vapor extraction for removal of VOCs from unsaturated soil.

5.1.5 Technology Summary

The technology screening process will culminate in the preparation of a Technology Summary which presents the results of the sitewide contamination data review and technology selection (as described above), and includes Statements of Work for treatability studies to be performed on the selected technologies. Two iterations of this screening and documentation process are planned, as described previously, leading to implementation of treatability studies for two groupings of technologies (practical, which is presented in this document, and innovative/emerging).

The Statements of Work for treatability studies will include an overview of the technology to be tested and the key environmental media contamination characteristics to be addressed by treatment. The specific objectives of the treatability study will be presented. The Statements of Work will include a description of the test approach in which approximate sample sizes, test equipment, potential logistical concerns, test sequencing and durations, and laboratory analyses are described. The Statements of Work will form the basis for preparation of the individual treatability study work plans.

Based on the limited site characterization data currently available, the first stage of technology selection focuses on practical, demonstrated technologies which are likely to have broad applicability to the site characteristics and types of contaminated environmental media at the Rocky Flats Plant. The Practical Technologies Summary is presented in Section 5.2; Statements of Work for conducting treatability studies on five practical technologies are presented in Section 6.1. The second stage of technology

selection will be expanded to consider innovative/emerging technologies as well as additional practical technologies using a more complete, validated database of site characterization information collected through the end of 1990.

Treatability studies conducted as part of the sitewide program will focus on technologies from which testing results would be useful in evaluating treatment effectiveness in upcoming CMS/FSs. Technologies known to be applicable and effective for the contaminants and environmental media of concern will not have Statements of Work prepared. These technologies will still be candidates for inclusion in pilot-scale treatability studies conducted as part of CMS/FSs for specific OU contamination problems.

5.2 PRACTICAL TECHNOLOGIES SUMMARY

This practical technologies summary presents the results of the technology selection process for practical (i.e., conventional) technologies that are likely to have broad applicability to site characteristics and types of environmental media contamination at the Rocky Flats Plant. A separate technology assessment report will be issued to incorporate the innovative and emerging technologies that are likely to be applicable for remediation at multiple OUs at the Rocky Flats Plant.

The technology selection process consisted of identifying, screening, and evaluating candidate treatment technologies. Available contamination data, primarily from OUs 1, 2, 4, 7, and 11 were used to identify candidate technologies. Based on the available data and the anticipated ARARs, target contamination problems that appear to exist on a sitewide basis were identified. A summary of the site contamination is presented in Section 5.2.1. The candidate technologies that were identified for the practical technology category are summarized in Section 5.2.2. A technology data sheet has been prepared for each candidate technology, and has been included as Appendix C in this

document. The technology screening process focused on identifying technologies for which treatability studies would be appropriate to aid in the evaluation of applicable technologies conducted as part of the Corrective Measures Study/Feasibility Study (CMS/FS) for each OU. The resulting list of selected technologies and the rationale for their selection are included in Section 5.2.3. For each of the five selected technologies, a statement of work was written to form the basis for preparing the detailed treatability study work plans that will be prepared prior to conducting the treatability studies. These statements of work describe, in general terms, the treatability testing approach and are presented in Section 6.1.

5.2.1 Selection of Target Contaminants

Target contaminants for use in the selection of practical technologies were identified based on a review of available site characterization data. Specific concentration data were only available for sites in OUs 1, 2, 4, 7, and 11. The maximum and minimum concentrations for water and soil within these combined OUs are listed in Table 4-1. Specific data by OU appears in Appendix A.

Because the site characterization data were incomplete and rather limited, the contaminants detected at elevated levels in OUs 1, 2, 4, 7, and 11 were used to select technologies. For practical purposes, the contaminants were divided into the following groups:

- Inorganics
- Metals
- Radionuclides
- Volatile organics
- Semivolatile organics.

All of these groups, except for semivolatile organics, have been detected at elevated levels in groundwater and surface water. From the inorganics group, nitrate, sulfate, and chloride have been detected at elevated levels in groundwater and both cyanide and nitrate in surface water. Metals of concern are mercury, chromium, selenium, nickel, manganese, copper, beryllium, zinc, lead, and iron for groundwater and mercury, chromium, copper, lithium, nickel, manganese, selenium, cadmium, arsenic and iron for surface water. Among the radionuclides, americium, plutonium, uranium, and tritium were identified as target compounds based on detections of all of these in surface water and in groundwater.

The volatile organic compounds (VOCs) that were identified as being of concern were carbon tetrachloride, 1,1-dichloroethylene, tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, chloroform, and vinyl chloride detected in groundwater and dichloromethane and tetrachloroethane detected at low levels in surface water. Nonhalogenated VOCs (e.g., benzene, toluene, ethylbenzene, and xylenes) were specifically tested for in groundwater but were not detected; however, toluene has been detected in the groundwater at OU1.

In soils, all contaminant groups have been detected. Cyanides, chloride, and nitrate were identified as target compounds from the inorganics group. The only confirmed metal contaminants are mercury, cadmium, iron, and antimony. Elevated concentrations of thallium have been reported. Radionuclides identified as target contaminants for soils were cesium, uranium, tritium, plutonium, strontium, and americium. Low concentrations of the semivolatile organics, fluoranthene, phenanthrene, and pyrene have also been reported. VOCs were included as target contaminants based on occurrences of tetrachloroethene and trichloroethene.

Limited information exists about actual wastes disposed at the Rocky Flats Plant site. Hazardous wastes have been disposed at various locations including, but not restricted

to, the present landfill. The following is a partial list of potentially hazardous materials at these sites:

- Empty chemical containers including solvent and reagent containers
- Unspecified metal chips
- Lathe coolant
- Spent mercury vapor lamps
- Uranium- and plutonium-contaminated sludge
- Uranium- and plutonium-contaminated soil and asphalt
- Waste and spilled fuel oil
- Asbestos (in out-of-service fuel oil tank)
- Photography lab wastes

Since the "waste" category is associated with specific sites within each OU and specific site characterization data for wastes are currently not available, treatment of materials classified as waste was not considered in this TSP, but will be considered later as data from the individual waste sites become available.

5.2.2 Practical Technologies and Applications

The approach used to identify candidate practical technologies entailed segregating the numerous contaminants at Rocky Flats into the five categories of contaminant types listed in Section 5.2.1. Practical technologies that have been used to treat the specific category of contaminants in full-scale facilities were then identified for each category in both water and soil media. These practical technologies, divided by medium treated, are given in Table 5-2. Detailed technology data sheets for all the practical technologies are presented in Appendix C with summaries of each technology presented below.

5.2.2.1 Water Technologies

Oxidation/Reduction of Inorganics, Radionuclides, and Metals - Chemical reduction-oxidation (redox) reactions are standard processes for breaking certain inorganics such as cyanide into their constituents, or for altering the oxidization state of metals to facilitate additional treatment. The oxidation state of heavy metals, such as chromium or plutonium, are typically adjusted to enhance a subsequent precipitation process. Nontarget organics and inorganics may also react creating undesirable side products and increasing the oxidant (or reductant) requirements.

Chemical Oxidation of Organics - Chemical oxidation is used to degrade hazardous organic materials generally to less toxic compounds. Oxidation systems, particularly those using ultraviolet (UV) light, ozone, and hydrogen peroxide, are powerful tools for treating a wide variety of common organic environmental contaminants. Disadvantages are similar to those for inorganic redox: nontarget organics and inorganics can produce undesirable side products and increase oxidant requirements.

Sorption of Inorganics, Radionuclides, and Metals - Sorption processes are used for treatment of inorganics, radionuclides, and metals and are based on the use of materials such as activated alumina and ferrite. These technologies have been used at various sites for treatment of wastewater and contaminated groundwater. Sorption processes are a means of removing contaminants from an aqueous stream. The sorption media are generally chemically regenerated which results in a concentrated side stream requiring further treatment or disposal.

TABLE 5-2
LIST OF CANDIDATE PRACTICAL TECHNOLOGIES

PRACTICAL TECHNOLOGIES FOR WATER

Inorganics

Oxidation Reduction (chlorination, aeration)
Sorption
Miscellaneous Physical/Chemical Processes
Reverse Osmosis
Electrodialysis

Radionuclides

Sorption
Ion Exchange
Reverse Osmosis
Chemical Precipitation

Metals

Chemical Precipitation
Reverse Osmosis
Electrodialysis
Sorption
Ion Exchange

Volatile Organics

Chemical Oxidation (UV/ozone/peroxide)
Granular Activated Carbon (GAC) Adsorption
Air Stripping
Steam Stripping
Distillation
Biological Treatment (closed system)

Semivolatile Organics

Chemical Oxidation (UV/ozone/peroxide)
Reverse Osmosis
Steam Stripping
GAC Adsorption
Biological Treatment (closed systems)
In Situ Biological Treatment (for groundwater)

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PRACTICAL TECHNOLOGIES FOR SOIL

Inorganics

Soil Washing

Radionuclides

Vitrification

Soil Washing (water, acid, chelating agents)

Solidification/Stabilization (silicate-based, pozzolanic-based)

Physical Separation (screening, classification, flotation, gravity separation)

Metals

Soil Washing (water, acid, chelating agent)

Solidification/Stabilization (silicate-based, pozzolanic-based)

Physical Separation (screening, classification, flotation, gravity separation)

Volatile Organics

Vacuum Extraction

Incineration

Biological Treatment (Land Treatment, Slurry Reactor)

Thermal Desorption

Semivolatile Organics

Incineration

Biological Slurry Reactor

In Situ Biological Treatment

Vapor Extraction (with Steam, Hot Air injection)

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Ion Exchange for Removal of Radionuclides and Metals - Ion exchange is a chemical process in which certain ions in aqueous solution are removed and replaced by other, more desirable, ions. For example, ionized uranium compounds can be replaced by chloride ions. This technology has been extensively used for treatment of wastewater and contaminated groundwater. The ion exchange resin used in this process is either chemically regenerated and reused in the process, or replaced with fresh resin. Either method results in a residual that must be further treated and/or disposed.

Miscellaneous Physical/Chemical Processes for Inorganics - This includes processes such as chemical coagulation, clarification, filtration, and ultrafiltration. These processes would be used either as a pretreatment step or as a post-treatment step in conjunction with other technologies discussed herein.

Granular Activated Carbon (GAC) Adsorption of Organics - GAC adsorption is the most widely used and developed technology for treating groundwater contaminated with organics. It is effective for the removal of a wide range of organics from aqueous waste streams. GAC is typically regenerated with a thermal process and the regeneration process can be performed with either off-site or on-site facilities.

Reverse Osmosis for Inorganics, Radionuclides, Metals, and Organics - Reverse osmosis processes involve the use of semipermeable membranes. By applying a pressure greater than the osmotic pressure, water is passed through the membrane while particulates, salts, and high molecular weight organics are retained. The retained, highly concentrated solution (retentate) contains dissolved salts, as well as the target contaminants, and requires further treatment or disposal.

Electrodialysis for Inorganics and Metals - Electrodialysis is a membrane process used for removal of ionic species from aqueous waste streams. An electrodialysis system consists of ion exchange membranes within an electrolytic cell. An electrical current is applied

across cation and anion exchange membranes resulting in a transport of ions through the membranes. The resultant side stream consists of high concentrations of the removed anions and cations which must be treated and disposed.

Chemical Precipitation for Radionuclides and Metals - Chemical precipitation is the process of making dissolved chemical compounds insoluble so that they can be separated from the liquid. Removal of metals and radionuclides from aqueous waste streams by precipitation is an established treatment method. Precipitation processes can often be tailored to treatment of individual contaminants. This process, however, does generate a sludge requiring treatment or disposal.

Air Stripping of Volatile Organics - Air stripping is a proven technology for removal of volatile and semivolatile contaminants from water. This process involves the transfer of contaminants from the contaminated liquid phase to the vapor phase by passing the two streams countercurrent through a packed tower. Air emission treatment is generally required with vapor phase activated carbon systems the most commonly used process for this purpose, but other alternatives, such as oxidation and incineration, exist. The vapor phase treatment unit is generally costly.

Steam Stripping of Volatile and Semivolatile Organics - Steam stripping involves injecting steam into a solution to volatilize organic compounds. It can be operated as a batch or continuous process. The use of steam makes it possible to strip compounds of lower volatility than those removed by air stripping. Steam stripping is a well demonstrated technology; however, it does generate a concentrate that requires treatment or disposal.

Distillation of Volatile Organics - Distillation is a process that involves separating compounds according to their boiling point characteristics. The primary use of distillation is for reclaiming spent solvents from industrial processes, and it is generally applicable only to rather concentrated solutions. The process can be used to separate

various volatile compounds or to separate mixtures of organics into light and heavy fractions. The light fraction can usually be recycled or used as a boiler feed, while the heavy fraction requires further treatment.

Biological Treatment (closed system) of Volatile and Semivolatile Organics - Biological reactors use microorganisms to remove organic contaminants from water. Most organic contaminants can be biologically degraded by the appropriate microorganisms. High concentrations of some organics or the presence of metals may be toxic to the organisms, and pretreatment may be required. Several different types of reactors exist, such as activated sludge systems, trickling filters, rotating biological contactors, and immobilized cell reactors. In general, these methods generate large amounts of sludge requiring disposal.

In Situ Biological Treatment for Semivolatile Organics - *In situ* biological treatment of groundwater involves the stimulation of biological growth in the contaminated zone in order to reduce the contaminant concentrations. Microorganisms that can use some or all of the contaminants as substrates will normally exist in a contaminated environment. The microorganisms are stimulated to increase their biological growth and consumption of contaminants through addition of essential nutrients. Aerobic systems also require an oxygen source. *In situ* treatment is dependent on geological and hydrological conditions. The process is relatively inexpensive, but the level of cleanup is generally lower than that achieved by biological reactors.

5.2.2.2 Soil Technologies

Physical Separation for Radionuclides and Metals - Soil contaminants are often found to be associated with particular size fractions of soils, most often the fine particles. In these cases, fractionation of the soil based on particle size can be an effective means of reducing the volume of the material that requires further treatment. The processes used for soil size fractionation include screening, classification, flotation, and gravity concentration. While physical separation is not actually a treatment process, it is being considered here because it may be a prerequisite to some of the other chemical, thermal, and other treatment operations; or it may be required for sample preparation for some of the treatability tests.

Soil Washing for Inorganics, Radionuclides, and Metals - Soil washing is based on the principle of contaminant removal from soil by washing with a liquid solution. Washing agents include water, acids, solvents, surfactants, or chelators. With the selection of appropriate washing solutions, soil washing technology can potentially be used to remove organics, inorganics, metals, and radionuclides. The wash solution containing the contaminants will require treatment and/or disposal.

Solidification/Stabilization for Radionuclides and Metals - Solidification is a process in which contaminants are mechanically bound to solidification agents, reducing their mobility. This produces a solid matrix of waste with high structural integrity. Stabilization usually involves the addition of a chemical reagent to react with the contaminant, producing a less mobile or less toxic compound. Solidification and stabilization are frequently used together and are a well established method for reducing the mobility and toxicity of hazardous wastes. This process generates large volumes of solidified materials requiring disposal.

Vitrification for Radionuclides - The vitrification process involves heating the waste matrix to a very high temperature and either combining the matrix with molten glass or heating the matrix until it melts. Once cooled, the molten mass solidifies into a stable, noncrystalline solid resistant to leaching of the inorganic, metal, and radionuclide contaminants. Organic components are destroyed by pyrolysis. The process can be conducted either *in situ* or off-site; however, the process is generally expensive.

Vacuum Extraction for Volatile and Semivolatile Organics - Volatile contaminants can be removed from soil using vacuum extraction, which is an *in situ* treatment technology that involves the air stripping of contaminants by inducing a vapor flow through the soil. Since this technology involves the transfer of contaminants to the vapor phase, air emission treatment is generally required. The efficiency of the process is highly dependent on the geologic conditions of the soil. This process can be enhanced by the injection of steam or hot air to facilitate semi-volatile organic removal.

Incineration for Volatile and Semivolatile Organics - Incineration is the controlled combustion of organic compounds under net oxidizing conditions (i.e., the final oxygen concentration is greater than zero). Temperatures in the incinerator are generally in the 1,200 to 2,300°F range which results in the destruction of organic compounds. Removal efficiencies for organics are generally greater than 99.99 percent, while metals are not destroyed but may be oxidized to a different form. Both metals and radionuclides may be emitted in the incinerator off-gas, or may be found in the solid residue. Incineration is a well developed, proven technology for treatment of organic compounds. This technology has been applied to solids, liquids, and gases, and is appropriate for the treatment of soils contaminated with organic compounds.

Thermal Desorption - This process uses various techniques to heat the soil and desorb the volatile organic contaminants. The process results in a contaminated air stream that requires additional treatment to remove or destroy the volatile organics. In one such

system, contaminated soils are excavated and processed through a pug mill or rotary drum system equipped with heat transfer surfaces. An induced airflow removes the desorbed volatile organics and transfers them to a carbon adsorption unit or incinerator.

Biological Treatment (slurry reactor) for Volatile and Semivolatile Organics - Soil contaminated with organics can be treated by microbial degradation in a biological reactor by mixing the soil with water to create a slurry. The slurry is agitated in the reactor to keep the solids in suspension, and the appropriate conditions for biological degradation are maintained. The slurry is dewatered when biodegradation is complete. The residual water may require treatment prior to disposal or reuse.

Biological Treatment (Land Treatment) for Volatile Organics - Soil contaminated with organics can be treated by microbial degradation in a biological land treatment unit by tilling, irrigating, and adding excavated soil. The tilling, irrigating, and adding nutrients maintain soil conditions in which biological degradation can be achieved. The leachate from the land treatment unit may require treatment prior to disposal or reuse in the system.

In Situ Biological Treatment for Semivolatile Organics - *In situ* biological treatment of soils involves stimulation of microbial growth in the contaminated, saturated soil zone by the addition of essential nutrients and possibly inocula of microorganisms. Oxygen addition is also required for aerobic systems. This method is typically used in conjunction with *in situ* groundwater treatment. Depending on the depth of soils to be treated, nutrient solutions can be added through sprinkling and subsequent infiltration or by a system of injection wells. As in *in situ* biological treatment of groundwater, *in situ* soil treatment is dependent on geological and hydrological conditions. The process is relatively inexpensive, but the level of cleanup is generally lower than that achieved by aboveground biological treatment.

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5.2.3 Selection of Technologies for Treatability Studies

The Treatability Studies Program is designed to identify and evaluate technologies that are broadly applicable for remediating the types of waste and contaminated media that exist at the Rocky Flats Plant. Treatability tests will be conducted on the selected candidate technologies and the resulting data analyzed to help expedite the CMS/FS process at each of the OUs. Guidance will be supplied on the format and content of the Treatability Study Work Plans that will be used for conducting all subsequent treatability studies.

5.2.3.1 Selection Criteria

The selection of practical technologies for treatability studies is based on the need for additional information to support technology, and for remedial alternatives evaluations during the CMS/FS to be conducted for each of the 16 OUs. The selection criteria are, therefore, derived from the following criteria which were used in the CMS/FS evaluation:

- Effectiveness
- Implementability
- Cost

Effectiveness refers to a technology's ability to treat a given volume of waste based on cleanup goals. The implementation criterion is used in this treatability study to eliminate technologies that are clearly unworkable or impossible to implement because of institutional or technical problems. Cost is not a significant factor in the initial phase of the CMS/FS and is not relevant for this first phase of treatability studies. The cost

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criterion will, however, be important for the screening of alternatives and the detailed analysis of alternatives, and treatability studies may be required for cost estimation purposes at that time. In summary, effectiveness and implementability are the key factors for the treatability study selection for alternatives evaluation.

Practical technologies selected for treatability studies are fully developed technologies that have not been sufficiently tested on the site-specific compounds, mixtures, or geological conditions to provide the information needed for the process suitability evaluation. Site-specific conditions for which there is insufficient information are typically related to radioactive and mixed contamination in soil and groundwater. Certain processes also require testing because of dependency on geological and other environmental conditions. The treatability tests will provide information on the effectiveness of a technology as it relates to a specific contamination problem. They will also indicate whether cleanup goals can be met, if additional technologies must be added to the treatment train, or if the technology should be eliminated altogether. Implementation problems, such as sidestream generation, will also be studied and evaluated. The treatability studies will support the decision to carry forward a technology or eliminate it from consideration.

5.2.3.2 Evaluation of Practical Technologies

The criteria in Section 5.2.3.1 were applied to the list of practical technologies presented in Table 5-2. Technologies identified for initial treatability studies are shown in Table 5-3. The following sections present the rationale for the selection or elimination of the practical technologies.

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TABLE 5-3
TECHNOLOGIES IDENTIFIED FOR TREATABILITY STUDIES

Inorganics, Radionuclides, and Metals in Water

Oxidation/Reduction and appropriate separation

Inorganics, Radionuclides, and Metals in Soil

Physical Separation (screening, classification, flotation,
gravity concentration)

Soil Washing (water, acid, chelating agents)

Solidification/Stabilization (silicate-based, pozzolanic-based)

Organics in Soil

Biological Treatment (bench-scale for semivolatiles)

5.2.3.3 Water Technologies

Oxidation/reduction of inorganics is a standard technology for which the implementability and effectiveness can be determined based on water quality data. Oxidation treatability studies for the target inorganics are, therefore, not required for the initial phase of the CMS/FS. However, it is likely that metals and radionuclides, for which the oxidation states generally are unknown, would be removed by oxidation/reduction processes. A study involving determining oxidation states of the target contaminants, evaluating effectiveness on mixtures of contaminants, and testing of various red-ox processes should, therefore, be performed prior to the FS evaluation. Oxidation is a proven technology for most target organics at Rocky Flats (with the exception of chlorinated VOCs), and treatability studies will not be needed for this class of contaminants until later phases of the CMS/FS.

Other inorganics that are present at elevated levels include cyanide, nitrates, and other anions such as chlorides, sulphates, and phosphates. Applicable technologies for these include reverse osmosis, ion exchange, and biological denitrification for nitrates. Since these constituents are treated by using numerous, well established technologies, they will not be considered in the sitewide treatability studies.

Sorption processes are established technologies for treatment of organics, inorganics, metals, and radionuclides and are not part of this TSP. Sorption treatability studies will be considered during the CMS/FS treatability studies.

GAC adsorption is a technology for which substantial information exists for numerous individual organic compounds. Data for some types of mixtures, such as chlorinated volatile organic compounds, however, do not exist. Additional wastewater data are needed to evaluate the applicability of GAC to organic contamination at the Rocky Flats

Plant site. This may be done later in the sitewide treatability studies or during the OU-specific studies.

Membrane processes such as reverse osmosis and electrodialysis are known to work for certain metals found at the site, and the alternatives evaluation can proceed based on existing information. None of these processes were selected for treatability studies in this initial phase, but based on additional water quality data will possibly be selected at a later stage of the CMS/FS process.

Chemical precipitation is a well documented technology that works for inorganics, metals, and radionuclides. Sufficient information exists to evaluate this technology as a CMS/FS alternative, but treatability studies may be needed in the technology screening phase to enable selection of the appropriate type of precipitation.

Air stripping is known to remove volatile organics, and steam stripping removes somewhat less volatile compounds. Their efficiencies can be estimated based on existing data, and no treatability study is needed prior to the design phase. Distillation is also a technology for which existing information is sufficient for evaluating it as a CMS/FS alternative.

Although biological treatment is a well established and practiced technology for a broad spectrum of organics, current sitewide contamination data indicate that halogenated volatile organics are the only problem organic contaminants in water. Biological treatment, both *in situ* and aboveground, is still considered innovative for these contaminants. These technologies will be evaluated as part of the innovative/emerging technology assessment.

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5.2.3.4 Soil Technologies

Physical separation is an important supplemental technology for treating contaminated soil efficiently by other technologies such as soil washing and solidification. The separation methods of screening and classification have, therefore, been selected for treatability studies in this phase.

Soil washing and solidification/stabilization treatability studies will be performed in conjunction with the physical separation studies. The effectiveness of soil washing is a function of physical, chemical, and mineralogical characteristics of the soil and the physical and chemical properties of the contaminant. Determination of soil washing effectiveness is only possible through testing of the actual material.

Similarly, solidification/stabilization effectiveness is also a function of the soil and contaminant concentrations. Determination of effectiveness of solidification in immobilizing contaminants requires treatability studies.

Vitrification has been applied to and proven for different radioactive and mixed wastes. Sufficient information exists to evaluate this technology as an CMS/FS alternative, but treatability studies particularly for *in situ* vitrification will be required for completion of the CMS/FS alternatives screening phase.

Vacuum extraction has been proven to work for the volatile organic contaminants and geological conditions at Rocky Flats. No treatability study will, therefore, be required until later in the CMS/FS process.

Incineration and thermal desorption are proven technologies for the organic contaminants found at Rocky Flats. The concentrations identified in the soil do not warrant consideration of these technologies at this time. These technologies will be

reconsidered should future site contamination data identify higher concentrations of organic contaminants.

Semivolatile organics have been identified at low concentrations in soil from Rocky Flats indicating that such compounds may pose a problem at the site. The following semivolatile organics have been identified with the limited site characterization data collected to date: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, fluoranthene, phenanthrene, phenol, and pyrene. Biological treatment via a biological slurry reactor is a proven technology for treatment of this class of contaminants and treatability studies will be performed unless additional analytical data demonstrate that the levels of semivolatile organics are not significant. Treatability studies are required to verify the effectiveness of biological treatment for site-specific samples.

The evaluation of *in situ* biological treatment will require the collection of specific site hydrogeologic data and is more appropriately evaluated by the individual OU CMS/FSs. Therefore, it will not be considered for treatability studies at this time.

5.2.3.5 Summary of Treatability Study Requirements

Table 5-4 shows the refined list of practical water and soil technologies. It also indicates which were selected and which remain for later treatability considerations or eliminated as treatability study candidates altogether. The technologies are divided into one of four categories. These are: no treatability study required; Stage I treatability study; future treatability study; or need additional site contamination data (identified as RI data). Those technologies listed as *no treatability study required* have been well established and can be evaluated based solely on contaminant concentrations. *Stage I treatability study* candidates are those technologies that, while practical, require treatability information to determine effectiveness for the site-specific compounds and mixtures or geological

TABLE 5-4

TREATABILITY STUDY REQUIREMENTS FOR PRACTICAL TECHNOLOGIES

Treatability Study (TS) Requirements for Practical Water Technologies

<u>Technology</u>	<u>No TS Required</u>	<u>Stage I TS</u>	<u>Future TS</u>	<u>Need Add'l RI Data</u>
Oxidation/Reduction of inorganics			X	
Oxidation/Reduction of radionuclides and metals			X	
Oxidation of organics			X	
Sorption of inorganics, radionuclides, and metals			X	
Sorption of organics			X	
Reverse Osmosis				X
Electrodialysis				X
Chemical Precipitation			X	
Air Stripping	X			
Steam Stripping	X			
Distillation	X			
Biological Reactor			X	
<i>In Situ</i> Biological Treatment			X	

Treatability Study (TS) Requirements for Practical Soil Technologies

<u>Technology</u>	<u>No TS Required</u>	<u>Stage I TS</u>	<u>Future TS</u>	<u>Need Add'l RI Data</u>
Physical Separation		X		
Soil Washing		X		
Solidification/Stabilization		X		
Vitrification			X	
Vacuum Extraction			X	
Incineration				X
Thermal Desorption				X
Biological Treatment		X		
<i>In Situ</i> Biological Treatment				X

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conditions. Technologies listed for *future treatability study* are those that are practical, applicable, and effective for currently identified site contaminants. These technologies, however, may require treatability studies at a future date for evaluation of pretreatment and post-treatment, cost, and size requirements. This information may be required during the alternatives development phase of the CMS/FS. Those technologies listed as *needing additional RI data* have been identified as practical technologies for treatment of the various general categories into which the contaminants of interest fall. At this time, however, either specific contaminants for which these technologies would be effective have not been identified as problem contaminants at the Rocky Flats Plant, or more detailed site-specific data, such as hydrogeologic information, are needed to adequately evaluate the technology.

6.0 FUTURE TREATABILITY STUDY WORK PLANS

The Future Treatability Study Work Plans are presented in this section. Statements of Work for each of the proposed treatability studies are discussed in Section 6.1, with a goal of establishing basic limitations for use in the later phases of the Corrective Measures Study/Feasibility Study (CMS/FS) to be conducted at each Operable Unit (OU). Section 6.2 presents guidelines for the preparation of Future Treatability Study Work Plans.

6.1 TREATABILITY STUDIES STATEMENTS OF WORK

The evaluation of the five practical technologies selected for treatability studies will be based on the relative effectiveness of the technology in reducing mobility, toxicity, and volume of the contaminated media in cases where more data is needed. The goal of these initial treatability studies will be to establish basic limitations of the technologies for use in the technologies and alternatives evaluation phases of the CMS/FS to be conducted at each OU.

All treatability studies will be performed according to data quality objective (DQO) levels II and III as defined by EPA guidance (EPA, 1987a). Analytical work associated with the treatability studies will follow the standard analytical protocol (EG&G Rocky Flats, 1990a) and quality assurance/quality control (QA/QC) procedures (EG&G Rocky Flats, 1990b) developed for the Rocky Flats Plant site.

The treatability testing will be performed with waste containing both median (or average) and high contaminant concentrations. Combinations of contaminants will also be studied where appropriate. Additional tests using synthetic mixtures may be used to supplement or

support information from initial runs on original waste material and provide multivariable analyses where appropriate.

6.1.1 Oxidation/Reduction

6.1.1.1 Introduction

This statement of work covers the bench-scale testing of oxidation/reduction processes to remove metals and radionuclides from surface water and groundwater at Rocky Flats. The review of existing data from OUs 1, 2, 4, 7, and 11 indicates that the heavy metals chromium, iron, mercury, nickel, selenium, and manganese and the radionuclides americium, plutonium, tritium, and uranium are present in surface and groundwaters at Rocky Flats in concentrations which exceed possible action levels. Of these, chromium, mercury, and plutonium are known to be amenable to treatment by reduction processes, while iron is treated by oxidation processes. Treatability testing will be performed on site at the Rocky Flats Plant or at an off-site laboratory possessing the necessary licenses, approvals, and notifications to perform hazardous waste treatability studies and handle radioactive materials.

6.1.1.2 Test Objectives

The primary objective of this testing will be to evaluate the relative effectiveness of the following four technologies in removing heavy metals and radionuclides from contaminated water:

- Oxidation/Precipitation
- Stannous chloride reduction
- Sulfur dioxide/metabisulfite reduction

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- Ferrous sulfate reduction.

The testing of oxidation/reduction processes for heavy metals and radionuclides will have the same two objectives: (1) oxidation/reduction of constituents to insoluble forms which can be readily removed from the water by settling or filtration and (2) oxidation/reduction to less soluble forms which can be subsequently removed by precipitation or coprecipitation, followed by settling or filtration. Thus, testing of the oxidation/reduction processes will be coupled with precipitation/coprecipitation and flocculation process testing to identify optimum heavy metal and radionuclide removal efficiencies by oxidation/reduction. Analysis of organic contaminants will also be conducted to determine the impact of this technology on these contaminants.

6.1.1.3 Test Approach

Oxidation/Precipitation

This test program will initially use small laboratory scale tests to oxidize and precipitate the heavy metals and radionuclides. Aeration will be used to add oxygen and precipitate iron. These initial tests will be done using multiple jar tests to determine the most effective type and dosage of coagulant and operating pH. The use of coagulant aids and polymers will also be evaluated.

Evaluation of performance during the initial tests will be based on visual observation of the rate of precipitate formation and settling. After the best apparent combinations of operating parameters has been established, additional tests will be performed with samples collected and analyzed to determine removal efficiencies. This will be followed by additional tests in which the precipitated and settled samples are filtered through 0.45

micron or smaller filter media to determine if increased removal efficiencies can be achieved.

If this process is demonstrated to be effective, pilot-scale testing during the individual operable unit CMS/FSs may be necessary to supplement these tests. At that time, sufficient quantities of sludges could be produced to evaluate alternative methods of treatment or disposal.

Reduction

Reduction tests will be conducted to evaluate the effectiveness of removing chromium, mercury, and plutonium from surface and groundwater. A series of jar tests will be conducted using the following reducing agents:

- Stannous chloride
- Sulfur dioxide/metabisulfite
- Ferrous sulfate.

Ionic mercury will be converted to the metallic form by reduction with stannous chloride and removed by filtration. Hexavalent chromium will be converted to trivalent chromium with sulfur dioxide, ferrous sulfate, or sodium metabisulfite. The conversion to trivalent chromium will be dependent on the time of reaction, pH of the reaction mixture, and concentration of the reducing agent. Removal of trivalent chromium is effected by precipitation.

The above reducing agents are also effective in reducing plutonium. Stannous chloride reduces plutonium (IV) to plutonium (III) and plutonium (VI) to plutonium (IV). Sulfur

dioxide reduces plutonium (IV) to plutonium (III) and plutonium (V) to plutonium (IV). Ferrous sulfate reduces plutonium (IV) to plutonium (III). The less soluble forms are plutonium (III) and (IV).

Tests with each of the above reducing agents will be performed by varying the dosages of reducing agent ranging in concentrations from 20 to 300 percent in excess of the stoichiometric need of the target contaminants. A sample volume of 3 to 5 liters will be required for each jar test. Samples will be tested at different pH levels for each dosage of reducing agent. Effluent samples from each test will be split in two to be analyzed for metals and radionuclides separately. The effluent sample to be tested for metals will be precipitated following reduction. The one to be tested for plutonium will be subjected to flocculation and settling after reduction.

6.1.2 Physical Separation

6.1.2.1 Introduction

This statement of work covers the testing approach to evaluate physical separation as a pretreatment step prior to soil washing or solidification/stabilization treatments for contaminated soils. Although the technology is primarily targeted for inorganics, metals, and radionuclides, it may also be effective in reducing the volume of organics-contaminated soil.

6.1.2.2. Test Objectives

These tests will evaluate the effectiveness of physical processes to separate contaminated soil fractions from noncontaminated soil fractions and reduce the amount of material being treated by soil washing or solidification/stabilization technologies. Separations between types of contaminants may also be possible, allowing different treatments on different

fractions. Tests will be conducted on the separation method and the size separation most likely to be useful in contaminated soil cleanup. Other physical separation processes, such as froth flotation and gravity (density) separation, have a limited range of applicability and may require feed characteristics that are unlikely to be found in contaminated soils. Preliminary characterization data, generated by sieve analyses, will be used to decide if size separation has a beneficial effect. Bench- or small pilot-scale separations will be run if sieve analyses show isolation of contaminants of concern into a size fraction. These tests will provide sufficient information for the initial phases of the CMS/FS process and will also prepare enough product for soil washing and solidification/stabilization tests.

6.1.2.3 Test Approach

Testing will be conducted in two phases, a characterization phase and a confirmation - "production" phase. The characterization phase will consist of sieve analyses with chemical and radionuclide analyses on the individual size fractions. Complete disaggregation of all of the particles is essential to the accuracy of these analyses. If the contaminants of concern are concentrated in a particular particle size fraction (range of particle sizes) as shown by their distribution, then physical separation may be useful in treating the soils. If the size fractions with lower concentrations of contaminants of concern meet cleanup criteria, and they constitute the majority of the material, a significant volume reduction can be achieved by making the size separation and by treating a smaller volume of soil that has higher concentrations of contaminants. It is expected that, if there is a size separation effect, the contaminants will be concentrated in the finest fractions, i.e., silts and clays.

The second phase of testing will have several purposes: primarily, confirmation of the results of the first phase; production of material for soil washing and solidification/stabilization tests; and development of data for pilot- and/or full-scale equipment sizing.

The first, or characterization, phase of physical separation testing will use a laboratory attrition scrubber to desegregate the soils to allow complete size separation. Attrition scrubbing is a process in which a water slurry containing a high concentration of solids is vigorously agitated. The particle-particle collisions in the slurry break up agglomerated fine materials and also scrub off fine particles that adhere to larger particles. The laboratory equipment typically available for attrition scrubbing cannot accept particles much larger than 2 millimeters; therefore, a preliminary wet screening step to remove large particles is necessary. This wet screening tends to wash fine particles off the large particles. While not as effective as attrition scrubbing, the residues of fines left on the coarse particles is generally insignificant. Wet screening is done on a vibrating screen with a continuous water wash. Either small vibrating screens (such as Sweco-type units) or standard sieves on a wet screen vibrator will be used as appropriate to the screen opening and amount of sample to be processed. Wet screening may be used at more than one stage of processing. The measurement of particle size distributions will follow the procedures described in ASTM D-422 (method for particle size analysis of soils), after the preparations described above.

The sequence of bench-scale testing of physical separation processing will include:

1. Soil sample preparation
2. Wet screening/separation of large diameter soil particles (>2 millimeters [mm])
3. Scrubbing of fine particles adhering to >2 mm fraction materials
4. Analysis of water soluble contaminants, clay, and silt content using standard procedures (EG&G Rocky Flats, 1990a)

5. Screening to determine particle size distribution of fine (<2 mm) materials
6. Analysis of contaminant distribution in the fine soil fractions using standard procedures (EG&G Rocky Flats, 1990a)
7. Evaluation of which contaminants are associated with the various size fractions.

The scrubbed size fraction greater than 2 mm would not be expected to contain a significant percentage of the constituents of concern. Depending on the percentage of total sample mass in the large size particle fraction, analysis for constituents of concern may be performed or may be omitted. The fraction of constituents not occurring in the scrubbing water and smaller size fractions may be assumed present in the greater than 2 mm material. Larger volumes of sample, as required to meet analytical and QA/QC requirements, will be used to verify initial results as to contaminant distribution and size gradations.

6.1.3 Soil Washing

6.1.3.1 Introduction

This statement of work covers testing of soil washing technologies for the removal of inorganics, metals, and radionuclides from contaminated soils either with or without preliminary physical separation. This statement of work is for laboratory- and bench-scale evaluations and does not cover field pilot testing. Soil washing for organics is considered an innovative/emerging technology and is not included in this practical technology treatability study.

6.1.3.2 Test Objectives

The objectives of this testing will be to evaluate several possible lixiviants and chelating agents for their effectiveness at removing contaminants of concern from contaminated soils, and to establish the best operating conditions for the effective agents. The effects of temperature, washing agent concentration, solid-liquid ratio in washing, and contact time will be investigated. Data will also be gathered on solid-liquid separation characteristics of the best systems. Loaded wash solution treatment and recycle/disposal issues will also be addressed. Although organics removal is not a test program objective, partitioning of organics between the washed soils and wash solutions will be analyzed to determine further treatment needs.

6.1.3.3. Test Approach

The testing will be conducted in several phases; the results of each phase will be passed on to the next phase. Available physical and chemical data for soil will be used to guide the selection of washing agents to test.

The first phase of the test will be screening tests to identify the most promising washing agents. The screening tests will be batch shaker tests conducted under the ideal conditions for each washing agent, with before and after measurements of the concentrations of the contaminants of interest. The washing agents that are ineffective in reducing soil contaminant concentrations will be eliminated in this step, while the others will be tested further. The analytical work in this phase will focus on target contaminants, radionuclides, and metals.

The second phase of bench testing will be a series of wash tests conducted with one or more of the washing agents. The washing will be operated as a batch or sequential process to

establish the optimum operating conditions for the process, including types and combinations of washing agents.

In the third phase of testing, conducted later as part of a CMS/FS for a specific OU, larger scale batch washes and small-scale continuous column washes will be conducted at the optimum conditions determined in Phase 2. These tests are used to provide data for pilot- and full-scale washing plant design, and to generate used wash liquor for recycling, treatment, and disposal testing.

The analytical work in Phases 2 and 3 will include analyses for organics that have been identified in the soil, in addition to metals and radionuclides. All analyses will follow standard procedures (EG&G Rocky Flats, 1990a).

Initial Wash Tests

Sample volume: As required, to ensure that every liquid and solid product fraction will be large enough to meet analytical and QA/QC requirements.

Type of test: Batch wash test

These tests will be run with high strength wash solutions and at generally high temperatures and high liquid-solid ratios to ensure maximum possible removal of contaminants from the soils. These tests will provide screening data to allow elimination of ineffective washing agents.

The tests will be conducted in beakers with completely mixed heated equilibrium contacting of the washing liquid with the soil samples. Residual inorganic, organic, heavy metal, and radionuclide constituents in the soil and in the filtered wash liquid will be analyzed.

Wash Optimization

This phase will consist of bench-scale, batch washes at various solution strengths, temperatures and solid-liquid ratios followed by sequential washing with different agents to determine the probable optimum conditions for the individual washing agents or combinations of washing agents. The test plan to be developed will include appropriate means of effective liquid/solids separation to simulate real process conditions.

These optimization tests will be run with soil samples, and various sizes and ranges of wash liquid volumes, testing temperatures, and agitation times.

6.1.4 Solidification/Stabilization

6.1.4.1. Introduction

This statement of work covers testing of solidification/stabilization agents for treatment of soils contaminated with inorganic constituents, metals, and radionuclides of concern. Included in this program is the testing of these agents on contaminated soil fractions that have been separated from the bulk of the soil by physical means. Agents to be tested will include both silicate-based and pozzolan-based agents, of nonproprietary and proprietary formulations. Testing of proprietary formulations may involve off-site tests at vendors' laboratories or on-site tests by vendor personnel. Companies that offer off-site laboratory solidification testing include International Waste Technologies (IWT) and Hazcon. Silicate Technologies Corporation of Arizona and Lopat Industries provide support for on-site testing. This plan covers laboratory characterization and bench-scale testing of mixtures for leaching, strength and durability characteristics. It does not include field, pilot-scale testing.

6.1.4.2 Test Objectives

The objectives of this program are to evaluate solidification/stabilization agents and additives to determine if contaminants in soils can be sufficiently immobilized by their use to meet regulatory criteria for disposal or replacement. Mixtures of contaminated soils and stabilization agents will be tested for leaching, strength, and durability characteristics. The results of these tests will be compared to regulatory and other criteria that may be applied in determining how the soil is to be handled. Leaching characteristics are important in determining whether the material can be left on-site or must go to a solid waste or hazardous waste landfill. Strength and durability criteria are imposed by some off-site landfills and will affect the design of any on-site repositories.

The tests will be focused on immobilization of heavy metals and radionuclides, but leaching of organic constituents will be tested to determine whether further treatment would be required.

6.1.4.3 Test Approach

The test approach assumes that leaching criteria are the most important; the agents and formulations are screened based on leaching results. Formulations that pass the leaching tests will then be tested for their performance regarding the strength and durability criteria.

Screening Tests

The screening tests will be conducted on the widest range of formulations, but only small amounts of soil will be required for each test. The soil samples will be mixed with the various agents at three different ratios with water being added in constant proportion to the amount of stabilization agent. A relatively short curing time of 24 hours will be used for comparison of leaching characteristics; however, longer cures will be used in the formulation

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optimization tests when strength characteristics are compared. After curing, the samples will be subjected to the appropriate leach procedure. The leachates will be analyzed for the contaminants of concern.

Solidification/stabilization agents that will be tested include nonproprietary agents such as portland cement, cement kiln dust, lime, and class C fly ash. Proprietary agents, such as those sold by Silicate Technology Corporation, will also be tested. Proprietary stabilization additives that are mixed with nonproprietary agents, such as those sold by Hazcon, Inc. and Lopat Industries, may also be included in the screening tests. Ratios of soil to stabilization agent will be varied over the range of 1:1 to 4:1. The ratio of water to stabilization agent will be kept constant for each agent. Different dosages of additives will also be tested with the dosage ranges based on recommendations from the proprietary vendors.

The leach test protocols will be determined by the regulatory requirements and cleanup goals for the soils in question. The Toxicity Characteristics Leaching Procedure (TCLP) is most likely to be the required leach test for RCRA hazardous materials, while the American Nuclear Society Short-Term Test procedure (ANSI/ANS-16.1-1986) may be applicable to radioactively contaminated soils and soils with mixed radioactive and hazardous contaminants.

The results of the leach tests will be used to select the agents and additives that will be used for formulations optimization. The formulations that meet leachability standards at lowest probable cost will be the starting points for further development.

Formulation Optimization

The results of the screening tests will be used to select a limited number of solidification agents for which optimum formulations will be developed. The optimization may depend more on physical criteria rather than leaching criteria. Sample volume requirements will

depend on the amounts of stabilized material needed for the various tests. Typically, 1 kg of mixture will be required for one TCLP leach and one unconfined compressive strength test. Standard cure times of 7 and 28 days will be used for all the physical characterization samples at this stage. Use of two cure times will allow comparison of the test mixtures on rate of development of strength and durability characteristics. Multiple cures will be tested for each mixture and cure time to gain information on variability of the characteristics achieved.

The leaching tests in this phase will follow the same protocols as in the screening tests. In addition, the basic unconfined compressive strength tests will be conducted as outlined in ASTM Standard D-2166. If durability of the solidified material is determined to be of importance, standard tests such as Methods for Freezing-Thawing Test for Soil-General Mixtures (ASTM D-560-82), Methods for Wetting and Drying Tests for Compacted Soil-General Mixtures (ASTM D-559-82), and Test Method for Slake Durability of Stakes and Similar Weak Rocks (ASTM D-4644) may be required. The goal of this testing is to find the lowest probable cost formulation that meets all of the soil cleanup criteria.

Confirmation Tests

To support the evaluation of this technology for CMS/FSs which are scheduled to be conducted after the sitewide study is completed, one or two formulations will be selected as optimum based on the formulation/optimization results and a final batch of that formulation will be mixed for confirmation by all relevant tests using DQO levels IV and V. A large batch of at least 5 kilograms will be required. From that batch, the various samples will be split before the mixture sets.

The same test criteria will be applied in this phase as in the previous phases. The primary differences will be in the amount of solidified mixture prepared and the level of QA/QC required. This phase will be essential in providing more definitive data on the performance

of this process at full scale. The results of this test phase may also indicate any unusual behavior that could be encountered in scale up of the process.

6.1.5 Biological Treatment

6.1.5.1 Introduction

This statement of work covers the testing approach to evaluate the applicability of biological treatment in a closed soil slurry reactor to remove semivolatile organics from contaminated soil. Target compounds could include benzo(a)anthracene, benzo(a)pyrene, benzo(b)-fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, fluoranthene, phenanthrene, phenol, and pyrene.

6.1.5.2 Test Objective

Biological treatment will be evaluated on the bench-scale to determine the feasibility of significantly reducing concentrations of the semivolatiles in soils. The fate of radionuclides, if present, will be traced throughout the testing period. If the radionuclides tend to concentrate in soil, then biological treatment may best be performed after treatment for radioactive elements. On the other hand, if radionuclides build up in the treatment water, necessary residual wastewater management should be addressed in later OU-specific treatability studies.

6.1.5.3 Test Approach

Bench-scale testing for biological treatment will be completed in three phases. During Phase 1, representative soil groups will be identified and characterized. Samples from each soil group will be tested for physical, chemical, and toxicity characteristics. Should the

toxicity testing in Phase 1 indicate extremely high toxicity (not substantially influenced by dilution anticipated for typical soil slurry mixtures), additional phases will not be completed. Phase 2 will simulate batch soil slurry reactor treatment along with land treatment and will establish optimum nutrient concentrations and evaluate oxygen sources. Finally, Phase 3 will simulate a continuous feed slurry reactor to identify the requirements of steady-state operation.

Characterization

Existing soil and contaminant data will be reviewed to establish three general soil groups based on levels of semivolatile organic contamination, radionuclide contamination, and estimated volumes. Representative soil samples will be analyzed to obtain baseline characterization information which will be used in establishing test environment parameters, e.g., toxicity and types of nutrients needed for biodegradation. Soil samples will also be tested for microbial toxicity using the Microtox assay to establish nontoxic soil/water proportions for reactor testing. The parameters to be tested for baseline characterization include:

Physical

- Soil type (percent clay, sand, etc.)
- Soil texture
- Bulk density
- Particle effective size.

Chemical

- Semivolatile compounds (target contaminants)
- Total nitrogen and phosphorus

- Total organic carbon
- pH
- Total petroleum hydrocarbons.

Batch Treatment Simulation

Slurry Reactor

Tests will be conducted in a 3-liter covered reactor. Contaminated soil will be transferred to the reactor, followed by an appropriate quantity of water to form a slurry. Air will be pumped into the reactor and the slurry mixture will be mechanically agitated. This will ensure maximum contact of the microbial population with the contaminated soil. Hydrogen peroxide or ozone may serve as an alternate source of oxygen. Nutrients will be added so that carbon:nitrogen and carbon:phosphorus ratios would be maintained at desired levels. Tests will be conducted at room temperature and at a pH of 6.5 to 8.0. Solids concentrations used in the tests could range from 10 to 40 percent, with the concentrations used determined by the soil type and the mixing energy applied to the test reactors to maintain the soil in suspension. Typical range of solids contents is 15 to 25 percent. Surfactants may be used to stimulate biological activity and to increase the solubility of hydrophobic compounds.

Land Treatment Unit

Tests will be conducted in a simulated laboratory land treatment unit test cell. This cell will be approximately 5 liters in volume and have an impermeable base. Contaminated soil will be placed in the test cell in an approximate 4-inch lift. Nutrients will be added in aqueous form so that the optimum moisture and carbon: nitrogen/carbon: phosphorous ratio are maintained at the levels predetermined during the characterization phase of this test. The

soil will be periodically tilled (turned over) to supply oxygen to the bacteria. All testing will be conducted at room temperature and the pH will be maintained between 6.5 and 8.0 standard units.

Compounds such as benzo(a)pyrene by itself cannot serve as the source of carbon and energy for the growth of microorganisms. This compound is amenable to biodegradation when other simpler hydrocarbon metabolites are present. The influence of cometabolites on target compound degradation will be investigated by using soils contaminated with cutting oils or by adding additional hydrocarbon cometabolites in small concentrations. Cometabolism is the concurrent metabolism of a carbon source capable of sustaining growth along with a compound that the microorganisms are unable to use as the sole carbon or energy source.

At intervals during the test period, samples of soil and water or leachate will be collected from the test cells and reactors and will be analyzed for the following parameters:

- Semivolatiles (target contaminants)
- Total organic carbon
- Dissolved organic carbon
- Microtox assay

The observed decreases in parent semivolatile compounds over time will be used to calculate degradation rate for these contaminants. A subsample from each of the tests will be tested for the oxygen uptake rate (OUR) using a respirometer. Based on the soil characterization data, biological degradation data, oxygen consumption rate, and carbon dioxide evolution, a mass balance will be performed at the end of each test. The microtox assay will be used as an indicator of the extent and rate of detoxification of the contaminated soil.

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The test duration will cover a period of 1 to 3 months. At the end of the test period, contaminants of concern will be analyzed. The results will be used to determine if biological treatment is effective in reducing the contaminant concentrations to a level to meet clean-up criteria. Analysis will also be conducted to evaluate the partitioning of the organics, and any heavy metals or radionuclides, between soil and water/leachate.

Triplicate reactors and test cells will be used for each test mixture. Averages and standard deviations will be calculated using these triplicate results.

The microbial biodegradation of contaminants may be limited because of constituents in the soil which inhibit microbial activity. If microbial inhibition occurs, follow-up treatability work would focus on identification of the toxic constituents (organics, heavy metals, salts, or radionuclides) and possible methods for pretreatment. If pretreatment is unavailable or inefficient, then the biological treatment process for soils would probably be eliminated from further consideration.

Steady State/Continuous Feed Simulation

The results of the batch treatment data will be used to establish a steady state/continuous feed bioreactor with a volume of 10 to 20 liters. The effect of soil feed rate, contaminant mass, etc., on the stability of the reactor will be evaluated using the key monitoring parameters established in Phase 2. The data collected from this phase will be used by the appropriate CMS/FS in the development and screening of remedial alternatives.

6.2 GUIDELINES FOR PREPARATION OF THE TREATABILITY STUDY WORK PLANS

Treatability testing will be conducted on each of the selected technologies to provide data to identify and evaluate appropriate remedial alternatives. Before conducting treatability

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testing for each technology, a Treatability Study Work Plan will be written. This plan will describe the manner in which the specific treatability test will be conducted. Although these treatability tests are not specifically a program in support of a CERCLA FS, the plans will generally conform to CERCLA Treatability Study guidance. The content of a typical Treatability Study Work Plan geared to laboratory screening and bench-scale testing is described in the following sections. The following 11 elements will be addressed in the plan: scope, test objectives, data quality objectives (DQOs), experimental procedures and equipment, data management, analysis of results, regulatory requirements for on-site/off-site testing, residuals management, Health and Safety Plan, Sampling and Analysis Plan, and reporting and scheduling. The following subsections describe the content of each of these elements.

6.2.1 Scope

The scope will provide an overall description of the treatability study. It will provide relevant background information on the site and summarize the existing waste characterization data (type, concentration, and distribution of contaminants of concern). It will specify the type of study to be conducted (laboratory, bench, or pilot). In addition, it will briefly describe the technology to be tested. A schematic flow diagram showing the material to be treated, the unit process being simulated, the main effluent streams, and any process residuals will be generated.

6.2.2 Test Objectives

This section will define the objectives of the treatability test and the intended use of the data. Treatability testing programs in which laboratory screening and bench-scale testing are undertaken usually have technology validation and/or performance evaluation as objectives. Technology validation involves obtaining a "yes" or "no" answer on whether the

technology is effective in treating the waste or contaminated media and should be considered further. Performance evaluation entails measurement of the success of treatment against established criteria in terms of treatment efficiency, effluent quality, or residual concentrations in the environmental medium. In assessing performance, objectives may also be set for reproducibility of treatment over the expected range of site and waste/media characteristics, as well as for quantitative and qualitative determinations on the resultant range of treatment residuals. The test objectives will be based on anticipated cleanup goals as determined by the potential ARAR determination or, when such goals do not exist, on levels that are protective of human health and the environment as determined by risk assessments, if available.

6.2.3 Data Quality Objectives

Data Quality Objectives (DQOs) will be specified in order to define the data quality needs of the project. In accordance with the EPA guidance document Data Quality Objectives for Remedial Response Activities (EPA, 1987a), a three-stage process will be used to develop the DQOs. In Stage 1, the types and magnitudes of decisions to be made will be determined. This process will entail evaluating the existing data and specifying the objectives of the treatability study (e.g., data quality needs would be different if the objective is to assess the validity of the technology or to confirm the attainment of a treatment standard). In Stage 2, the criteria for determining data adequacy will be stipulated and the sampling approaches and analytical procedures will be selected. During Stage 3, the methods for obtaining data of acceptable quality and quantity will be selected and incorporated into and the Quality Assurance Addendum (QAA) of the Treatability Study Work Plan.

The five analytical levels that are established in the EPA's DQO guidance are included as Table 6-1 and will be applied to the treatability studies. When laboratory screening studies

are being performed, analytical levels I and II will be used. Confidence limits will be wide (± 25 percent) in keeping with the characteristics of this level of study (i.e., low cost, quick turnaround, and limited quality assurance/quality control [QA/QC]). When bench-scale tests are required, analytical levels II through V may be used.

Confidence limits will be narrower to meet the quantitative objectives of obtaining more detailed waste characterization and performance testing data. However, even in bench-scale work, data quality for some samples and unit processes may be allowable at lower levels. This is based on necessary turnaround times for use of the data in process decisions or based on the nature of the process under study or its performance objective. The objectives and limitations of using the lower analytical levels must be described in the treatability study work plans.

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TABLE 6-1. SUMMARY OF ANALYTICAL LEVELS*

Level I	
Type of analysis	Field screening or analysis with portable instruments.
Limitations	Usually not compound-specific, but results are available in real time. Not quantifiable.
Data quality	Can provide an indication of contamination presence. Few QA/QC requirements.
Level II	
Type of analysis	Field analyses with more sophisticated portable instruments or mobile laboratory. Organics by GC, inorganics by AA, ICP, or XRF.
Limitations	Detection limits vary from low parts per million to low parts per billion. Tentative identification of compounds. Techniques/instruments limited mostly to volatile organics and metals.
Data quality	Depends on QA/QC steps employed. Data typically reported in concentration ranges.
Level III	
Type of analysis	Organics/inorganics performed in an off-site analytical laboratory. May or may not use CLP procedures. Laboratory may or may not be a CLP laboratory.
Limitations	Tentative compound identification in some cases.
Data quality	Detection limits similar to CLP. Rigorous QA/QC.
Level IV	
Type of analysis	Hazardous Substances List (HSL) organics/inorganics by GC/MS, AA, ICP. Low parts-per-billion detection limits.
Limitations	Tentative identification of non-HSL parameters. Validation of laboratory results may take several weeks.
Data quality	Goal is data of known quality. Rigorous QA/QC.
Level V	
Type of analysis	Analysis by nonstandard methods.
Limitations	May require method development or modification. Method-specific detection limits. Will probably require special lead time.
Data quality	Method-specific.

*Source: EPA, 1987a (modified).

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6.2.4 Experimental Procedures and Equipment

This section will describe the experimental design, the methodology, and the equipment that will be used during testing. The discussion on experimental design will identify the volume of waste material to be tested, the critical parameters, the levels of testing, and the type and amount of replication. The methodology discussion will include the types of methods that will be used; the specific steps, however, that will be followed during testing will be described in the standard operating procedures (SOPs). The SOPs will be appended to the treatability study work plan or, if published in earlier work plans, incorporated by reference. A list of the equipment, materials, and reagents will be prepared and will include the specifications for each item (e.g., quantity, volume/capacity, calibration or scale, equipment manufacturer and model number, and reagent grade and concentration). The measurements to be taken during the tests and the samples to be taken for laboratory analysis (number, size, time, and preparation methods) will also be specified.

The logistics of testing will be described in this section, while the details of collecting the samples to be tested will be described in Section 6.2.10. The locations where waste or contaminated media samples are to be obtained, or the sector of the contaminated area to be studied, will be identified on a site map and one or more cross sections. The on-site or off-site testing location will be described in terms of the facilities supplied, manpower involved in conducting the tests, sample storage areas, and other pertinent details. If a proprietary treatment process is being tested, any limitations on knowledge of the process operation or reagents used will be discussed.

6.2.5 Data Management

The section on data management will describe the procedures for recording observations and raw data in the field or laboratory including the use of bound notebooks, data collection sheets, and photographs. If proprietary processes are involved, this section will also describe how the confidential information will be handled and what data will be supplied by the vendor. Analytical data will be supplied both in hard copy and on a computer diskette, if voluminous. Data tables generated for both field and laboratory data will be checked against the source document using procedures outlined in this section.

6.2.6 Analysis of Results

The analysis of results section will describe the approach that will be used to present and interpret the data upon completion of the treatability test. It will describe how the data will be summarized and evaluated to determine the validity or performance of the treatment process. It will describe the data-checking process that will be used to assess all data for precision (relative percent difference for duplicate matrix spikes), accuracy (percent recovery of matrix spikes), and completeness (percentage of data that are valid). In addition, if data are to be generated on cost (i.e., reagent use, power and water consumption, treatment rate, etc.) or equipment design (i.e., waste feed, mixing, solids separation, etc.), it will discuss how the test data will be analyzed to yield these results.

This section will also describe the statistical analysis procedures that will be followed, if applicable. If laboratory screening is to be conducted, a statistical analysis of the data will not be appropriate. However, the results will be interpreted qualitatively and described as such. If bench-scale or pilot-scale testing is to be conducted, a statistical analysis will generally be appropriate and, therefore, the procedures will be described.

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6.2.7 Regulatory Requirements for On-Site and Off-Site Testing

Treatability studies for RFP wastes will be subject to CERCLA requirements and possibly to RCRA permitting and operating requirements. These requirements will vary depending on whether the studies are conducted on-site or at an off-site laboratory or testing facility.

When off-site treatability studies must be conducted, sample collection and shipping restrictions will be followed to comply with the Sample Exclusion Provision (40 CFR 261.4(d)) of RCRA. This provision, which exempts waste samples collected for the sole purpose of determining their characteristics or composition from regulation under Subtitle C of RCRA, has been expanded to include waste samples used in small-scale treatability studies (53 FR 27301). This expanded provision is referred to as the Federal Treatability Study Exemption Rule. In accordance with this rule, samples that are collected, stored, or transported to an off-site laboratory or testing facility will be exempt from the RCRA generator and transporter requirements (40 CFR Parts 262 and 263) by following these guidelines:

- Do not collect or ship more than 1,000 kilograms (kg) of any nonacute hazardous waste, 1 kg of acute hazardous waste, or 250 kg of soils, water, or debris contaminated with acute hazardous waste per waste stream per treatment process.
- Check the sample package. It must not leak, spill, or vaporize from its packaging during shipment, and the transportation of each sample shipment must comply with U.S. Department of Transportation (DOT), U.S. Postal Service (USPS), or any other applicable regulations for shipping hazardous materials. All sample packages must be surveyed for radioactivity following

Rocky Flats Plant and DOT requirements. Packages must be appropriately labelled after surveys, according to DOT regulations (49 CFR 173).

- Check the permit status of the laboratory or testing facility. The samples can only be shipped to a laboratory or testing facility that is exempt under 40 CFR 261.4(f) or that has an appropriate RCRA permit or interim status. If the samples are anticipated to contain radionuclides, all laboratories (including analytical laboratories) handling the samples must be licensed by the Nuclear Regulatory Commission (NRC) or the applicable state agency if they have NRC licensing authority for handling, analyzing, treating, or storing radioactive materials. The license must be inclusive of the radionuclides expected and allow amounts of those radionuclides in excess of the quantities anticipated.

When on-site treatability studies are to be conducted, substantive compliance with Federal, state, or local requirements will be demonstrated. If necessary, permits will be obtained. Treatability studies requiring sample amounts in excess of the Federal Treatability Study Exemption Rule must be conducted on-site. Additionally, it may be preferred to conduct some studies on-site because of the types of contaminants anticipated or the technology to be tested.

For each treatability study conducted, the following information must be maintained for each individual waste stream:

- The date the sample was collected
- The date the sample was received at the treatability study unit

- Total quantity in kg of "as received" waste in storage per day at the treatability study facility
- If the "as received" waste sample was stored prior to initiating the treatability test, where it was stored
- Quantities and types of waste subjected to treatability studies
- Date treatment was initiated, and the amount of "as received" waste introduced to treatment each day. (If the treatment process is conducted in a glovebox AND an individual sample is treated in multiple runs, THEN the day the entire sample enters the glovebox is the date of treatment initiation for the sample)
- Dates of initiation and conclusion of each treatability test
- Final disposition of residues and unused sample from each treatability study (such as which RCRA-permitted hazardous waste storage area are the residues and unused samples stored in)
- Records of any spills or releases
- Records must be kept for a minimum of 3 years after completion of each treatability study that show compliance with the treatment rate limits, and the storage time and quantity limits.

This recordkeeping information will be included in the annual report to the CDH by March 15 of the following year. In addition to the following information, the annual report identifies the treatability studies proposed for the current year.

Monthly reporting will be required for each treatability study. These reports will include the following:

- Waste stream studied
- Treatability test number
- Date sample collected
- Where sample stored prior to treatment
- Date treatment initiated
- Initial sample weight
- Date treatment concluded
- Final residue and unused sample weight
- Where residue stored prior to return to permitted storage area
- Date residue returned to permitted storage area.

This information will be presented in a table format with one table per waste stream/process. This information will be provided to EG&G RCRA Permitting Division on a monthly basis. The state will also be notified of the intent to conduct any new treatability study. The RCRA Permitting Group will submit the notifications.

6.2.8 Residuals Management

A section on residuals management will be included to describe the management of all treatability study residuals including unused waste not subjected to testing; treated waste; treatment residuals; laboratory samples and sample extracts; used containers or other expendables; and contaminated protective clothing and debris. It will include estimates of both the types and quantities of residuals expected to be generated during treatability testing based on knowledge of the treatment technology and the experimental design. The residuals management section will consider the status of testing residuals relative to RCRA waste characterization and disposal requirements. It will describe how treatability study residuals will be analyzed to determine if they are hazardous wastes or contain hazardous substances at levels of concern relative to disposal, and will specify whether such wastes will be returned to the site or shipped to an acceptable treatment, storage, or disposal facility (TSDF) permitted under Subtitle C of RCRA. In the latter case, this section will also identify the waste generator and delineate the parameters that will be analyzed for properly manifesting the waste and for obtaining disposal approval.

Some samples and residuals may contain only radioactive contamination and others may be "mixed" wastes, meeting RCRA hazardous waste definitions and containing radioactive components. These materials cannot be disposed as RCRA wastes. All residuals must be screened for radioactivity prior to any decision on disposal. Any original samples and any residuals meeting the definition of a radioactive material in

49 CFR 173.403 must be returned to the Rocky Flats Plant, regardless of their status as hazardous waste.

Off-site laboratories will be allowed to return any unused sample or residues to the Rocky Flats Plant under the Treatability Study Sample Exemption Rule if storage time limits are not exceeded. In accordance with 40 CFR 261.4(f), the laboratory or testing facility must not exceed the storage time limit of 90 days from the time the treatability study was completed, or no more than 1 year from the sample shipment date from the Rocky Flats Plant to the facility.

The residues or unused samples generated from on-site treatability studies will be managed as RCRA hazardous wastes. This regulation requires that residues or unused samples from the treatment process must not be stored at the treatability test location for more than 90 days. However, residues can be stored in a RCRA-permitted storage area indefinitely or until manifested and shipped off-site for disposal.

6.2.9 Health and Safety Plan

A section will be included that describes how health and safety procedures will be used to address the hazards associated with treatability testing. This Health and Safety Plan (HSP) will be prepared in accordance with the EG&G Environmental Restoration Sitewide Health and Safety Program Plan. Hazards addressed include, but are not limited to, chemical or radiological exposure; fires, explosions, or spills; generation of toxic or asphyxiating gases; physical hazards; electrical hazards; and heat and cold stress. The HSP will include procedures for treatability studies that are conducted on site or at an off-site laboratory or testing facility permitted under RCRA, including research, development, demonstration facilities, and facilities that are conditionally exempt from Subtitle C regulation by the treatability study sample exemption. Health and safety at

off-site facilities will be addressed to the extent necessary to (1) ensure adequate response to any special hazards imposed by the samples or treatability testing procedures, and (2) protect and inform personnel involved in the performance of the treatability testing.

6.2.10 Sampling and Analysis Plan

A Field Sampling Plan (FSP) will be written to define the field sampling objectives and procedures. It will include the sampling objectives; the type, location, and number of samples to be collected; the sample numbering system; the necessary equipment and procedures for collecting the samples; the sample chain-of-custody procedures; and the required packaging, labeling, and shipping procedures. The field sampling procedures described in the FSP will be in accordance with the ER Program Standard Operating Procedures.

A QAA will be written in accordance with the Rocky Flats Plant ER Quality Assurance Program Plan and Project Plan. It will detail the analytical requirements and the quality assurance objectives (precision, accuracy, representiveness, completeness, and comparability) for critical measurements. It will also describe the quality control procedures that have been established to achieve the desired QA objectives for a specific treatability study.

6.2.11 Amendment of Quality Assurance Plans

The Environmental Restoration Department uses a three-tiered approach to quality planning and monitoring. The first tier consists of the Environmental Restoration (ER) Quality Assurance Program Plan (QAPP) which provides general guidelines and requirements for quality-related and quality-affected activities for the ER program. The

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second tier involves implementation of this plan through a department-specific quality assurance (QA) program. A second-tier QA document, a QAPjP, identifies the planned system of QA/QC requirements, procedures, and policies for ensuring the quality and reliability of reports, measurement data, and environmental documentation developed for the Rocky Flats Plant studies. The third tier consists of activity-specific QAAs that describe the detailed procedures used for particular activities, projects, site investigations, etc. It is these QAAs that describe in detail how the QA controls will be implemented including applicable work instructions, procedures, and documentation.

In accordance with the IAG, the specific QAPjP developed for the RFI/RIs conducted in parallel with the Treatability Studies Program at the individual OUs will be reviewed and modified to incorporate treatability study requirements, as necessary. Additionally, the QAPjP will be amended to incorporate these requirements, as necessary.

6.2.12 Reporting and Schedules

This section will describe the preparation of interim and final reports documenting the results of the treatability study. Interim reports will only be generated when the treatability studies on a selected technology involve more than one tier (e.g., laboratory screening followed by bench-scale testing). In this case, interim reports will provide a means for determining whether to proceed to the next level of testing. In addition, the preparation of monthly reports that detail current and projected progress on the project will be described.

The EPA-suggested organization of the final treatability study reports will be followed, and is included as Table 6-2. This format includes four major sections: Introduction; Conclusions and Recommendations; Treatability Study Approach; and Results and Discussion. The suggestions concerning the content of each of these sections, which is

TABLE 6-2. SUGGESTED ORGANIZATION OF THE TREATABILITY STUDIES REPORT¹

1. Introduction
 - 1.1 Site description
 - 1.1.1 Site name and location
 - 1.1.2 History of operations
 - 1.1.3 Prior removal and remediation activities
 - 1.2 Waste stream description
 - 1.2.1 Waste matrices
 - 1.2.2 Pollutants/chemical
 - 1.3 Remedial technology description
 - 1.3.1 Treatment process and scale
 - 1.3.2 Operating features
 - 1.4 Previous treatability studies at the site
2. Conclusions and Recommendations
 - 2.1 Conclusions
 - 2.2 Recommendations
3. Treatability Study Approach
 - 3.1 Test objectives and rationale
 - 3.2 Experimental design and procedures
 - 3.3 Equipment and materials
 - 3.4.1 Waste stream
 - 3.4.2 Treatment process
 - 3.5 Data management
 - 3.6 Deviations from the work plan
4. Results and Discussion
 - 4.1 Data analysis and interpretation
 - 4.1.1 Analysis of waste stream characteristics
 - 4.1.2 Analysis of treatability study data
 - 4.1.3 Comparison to test objectives
 - 4.2 Quality assurance/quality control
 - 4.3 Costs/schedule for performing the treatability study
 - 4.4 Key contacts

References

Appendices

- A. Data summaries
- B. Standard operating procedures

¹EPA Guide for Conducting Treatability Studies Under CERCLA (1989)

included in the EPA Guide for Conducting Treatability Studies under CERCLA (1989), will be used as a general guideline. The report will provide only limited information on the applicability of the technology to specific OUs at the Rocky Flats Plant. Application of this information to specified OUs will generally be left for the decision process in each CMS/FS.

The schedules for preparation of each work plan, performance of the requisite testing programs, and reporting of results will conform to the schedule shown in Section 7.0, Table 7-1.

7.0 DELIVERABLES AND SCHEDULE

The Rocky Flats Draft Inter-Agency Agreement (IAG) dated August 17, 1990 calls for draft and final sitewide treatability studies plans in 1990 and reporting of results in 1993. Preliminary draft submittals for Rocky Flats Plant review will precede document submittals as drafts to Region VIII Environmental Protection Agency (EPA) and the Colorado Department of Health (CDH).

The schedule and deliverable documents for the Sitewide Treatability Studies Program are shown in Table 7-1. The revision of the Treatability Studies Plan (TSP) during August through October 1990 was based on a review of a limited database of site contamination data, principally from OUs 1, 2, 4, 7, and 11. This review was conducted initially to permit the selection of practical technologies in Section 5 of this document. A more comprehensive review of existing site contamination data and potential Applicable or Relevant and Appropriate Requirements (ARARs) will be performed early in 1991 to facilitate the identification and screening of innovative and emerging technologies. Other sitewide program documents will be issued in final form on or after the scheduled submittal date for the (TSP) including:

- The Health and Safety Plan (HSP) final submittal on November 21, 1990
- The Quality Assurance Project Plan (QAPP) and associated Standard Operating Procedures - final submittal on January 2, 1991.

In accordance with IAG requirements for the TSP, a review of these documents for adequacy of their provisions to address the health and safety and QA/QC needs for treatability work will be conducted after submittal of the plan. Recommendations for

**TABLE 7-1
TREATABILITY STUDIES PROGRAM SCHEDULE**

Submittal Dates	Description
May 25, 1990	Preliminary Draft Treatability Studies Plan and Statements of Work - Practical Technologies to Rocky Flats Plant
Sept. 21, 1990	Draft Treatability Studies Plan (TSP) to Agencies
Feb. 25, 1991	Final Treatability Studies Plan (TSP) to Agencies
May 26, 1993	Draft Treatability Study Report to Agencies
Oct. 20, 1993	Final Treatability Study Report to Agencies

revisions or addenda to these supporting sitewide documents will be made in a separate memorandum to Environmental Restoration (ER) program management at the Rocky Flats Plant.

Both practical and innovative/emerging treatment technologies (as defined in Section 5.0) will be included in the sitewide treatability studies, with technology evaluation-level studies (usually bench-scale testing) planned for the 1991-1992 study period. The first round of studies, to be conducted over a 1-year period, will include practical technologies described in the Statements of Work, Section 6.1.

The second round of studies, also to be conducted over a 1-year period, will include additional practical technologies as well as innovative/emerging technologies identified in the early 1991 analysis of existing site contamination data and potential ARARs. Additional treatability work involving systems analysis-type studies will be conducted, as needed, directly on contamination problems associated with the individual OU CMS/FSs. However, most of the CMS/FSs are scheduled to occur after the sitewide treatability studies as separate programs.

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APPENDIX A
ANALYTE CONCENTRATIONS AT THE MAJOR SOLID
WASTE MANAGEMENT UNITS OF OPERABLE UNITS 1, 2, AND 3

TABLE 1-1¹

OU CROSS REFERENCE LIST

<u>Old OU Number</u>	<u>New OU Number</u>	<u>Description</u>
01	01	881 Hillside Area
02	02	903 Pad Area
10	03	Off Site Areas
03 Solar Ponds	04	Solar Ponds
04 Woman Creek	05	Woman Creek
04 Walnut Creek	06	Walnut Creek
03 Present Landfill	07	Present Landfill
05	08	700 Area
03 Original Process Waste Line	09	Original Process Waste Line
03 Other Outside Closures	10	Other Outside Closures
03 West Spray Field	11	West Spray Field
06	12	400/800 Area
07	13	100 Area
09	14	Radioactive Sites
03 Inside Building Closures	15	Inside Building Closures
08	16	Low Priority Sites

¹ As a result of IAG negotiations, the OU numbering system of December 1989 was modified. The OU system used in this report is the new numbering system first printed in August 1990. The numbering systems are cross-referenced in Table 1-1.

TABLE A-1: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 1

PARAMETERS	881 HILLSIDE MAXIMUM			881 HILLSIDE MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
INDICATORS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
pH (pH units)	8.5	10.14	..	5.98	9.02	NR
Silica	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	2374	480	NR	<163	..	NR
INORGANICS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Bicarbonate as CaCO ₃	502	232	NR	<73.9	..	NR
Carbonate as CaCO ₃	NR	6	NR	NR	<5	NR
Chloride	838	77	NR	<2.9	..	NR
Cyanide	..	ND	NR	<.0036	<.0025	NR
Nitrate as N	NR	NR	NR	NR	NR	NR
Nitrate+Nitrite as N	55	8	NR	<0.02	..	NR
Sulfate	700	80	..	<24.8	..	..
RADIONUCLIDES	pCi/l	pCi/l	pCi/g	pCi/l	pCi/l	pCi/g
Americium 241	0.03	..	0.15	<0.01	..	..
Cesium 137	..	..	2.6	<0.78	..	..
Gross Alpha	319	16	..	<2.0	..	..
Gross Beta	286	12	41	<4.0	..	..
Plutonium 239+240	0.13	..	4.8	<0.01	..	..
Radium 226	NR	0.5	NR	NR	..	NR
Strontium 90 - A	5.6	..	1.9	<1.0	..	..
Thorium 230+232	NR	NR	NR	NR	NR	NR
Tritium	777	NR	0.73	<400	NR	..
Uranium (total)	58.9	NR	NR	<1.8	NR	NR
Uranium 233+234	28	5	60
Uranium 235	4.3	0.6	NR	NR
Uranium 238	24	4.5	3000

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A - Strontium 89, 90 for soils

TABLE A-1: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 1 (cont.)

PARAMETERS	881 HILLSIDE MAXIMUM			881 HILLSIDE MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
METALS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Aluminum	..	..	22000	<0.029	..	..
Antimony	0.078	ND	21	<0.006J	<.06	..
Arsenic	0.01	..	19	<0.01	..	..
Barium	0.18	..	811	<0.038	..	..
Beryllium	.003J	0.017	1.9	<0.005	..	..
Boron	NR	NR	NR	NR	NR	NR
Cadmium	0.0017	..	9	<0.005	..	..
Calcium	355.99	299	72551	<24.18	..	..
Cesium	.04J	..	NR	<0.02	..	NR
Chromium	0.078	0.067	27.8	<0.01	..	..
Cobalt	ND	..	36	<.05	..	..
Copper	0.95	..	..	<0.0063	..	..
Germanium	NR	NR	NR	NR	NR	NR
Iron	0.41	..	67200	<0.0069	..	..
Lead	0.024	..	35.2	<0.005	..	..
Lithium	0.7	..	NR	<0.001J	<.10	..
Magnesium	95.5	19.2	6490	<5.4617	..	..
Manganese	0.96	..	..	<0.0051	..	..
Mercury	0.9	..	2.07	<0.0001J	..	..
Molybdenum	0.053	..	..	<0.022	..	..
Nickel	1.18	..	71	<0.037	..	..
Niobium	NR	NR	NR	NR	NR	NR
Potassium	12.3	9.88	3040	<0.5	..	..
Rubidium	NR	NR	NR	NR	NR	NR
Selenium	3.2	..	0.5	<0.002J	<.005	..
Silver	0.0094	..	0.9	<0.0076	..	..
Sodium	341.76	43.2	2230	<21.12	..	..
Strontium	2.91	0.6	209	<0.14	..	..
Tantalum	NR	NR	NR	NR	NR	NR
Tellurium	NR	NR	NR	NR	NR	NR
Thallium	0.01	..	0.934	<.01	<.01	..
Tin	ND	..	..	<.1	..	..
Titanium	NR	NR	NR	NR	NR	NR
Tungsten	NR	NR	NR	NR	NR	NR
Vanadium	0.037	..	49	<0.024
Zinc	2.46	0.051	185	<0.02
Zirconium	NR	NR	NR	NR	NR	NR

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A - Strontium 89, 90 for soils

TABLE A-1: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 1 (cont.)

PARAMETERS	881 HILLSIDE MAXIMUM			881 HILLSIDE MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
SEMI-VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
Benzo(a)anthracene	NR	NR	NR	NR	NR	NR
Benzo(a)pyrene	NR	NR	NR	NR	NR	NR
Benzo(b)fluoranthene	NR	NR	NR	NR	NR	NR
Benzo(g,h,i)perylene	NR	NR	NR	NR	NR	NR
Benzo(k)fluoranthene	NR	NR	NR	NR	NR	NR
Fluoranthene	NR	NR	NR	NR	NR	NR
Indeno(1,2,3-cd)pyrene	NR	NR	NR	NR	NR	NR
Phenanthrene	NR	NR	NR	NR	NR	NR
Phenol	NR	NR	NR	NR	NR	NR
Pyrene	NR	NR	NR	NR	NR	NR
VOLATILES (1)	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
1,1-Dichloroethane	180	ND	NR	<5	<5	NR
1,1-Dichloroethylene	7900	ND	NR	<5	<5	NR
1,1,1-Trichloroethane	15000	ND	110	<5	<5	NR
1,1,2-Trichloroethane	47	ND	NR	<5	<5	NR
1,1,2,2-Tetrachloroethane	5	ND	NR	<5	<5	NR
1,2-Dichloroethane	17	ND	NR	<5	<5	NR
2-Butanone	ND	ND	NR	<10	<10	NR
Acetone	19B	2	NR	<10	<10	NR
Carbon Disulfide	3J	ND	NR	<5	<5	NR
Carbon Tetrachloride	2400J	ND	NR	<5	<5	NR
Chloroform	ND	1	NR	<5	<5	NR
Chloromethane	ND	ND	NR	<10	<10	NR
Dichloromethane	17	13	NR	<5	<5	NR
Methyl Ketone	NR	NR	NR	NR	NR	NR
Tetrachloroethene	5900	8	190	<5	<5	NR
Toluene	ND	2	NR	<5	<5	NR
Trichloroethene	11000	ND	150	<5	<5	NR
Vinyl Chloride	ND	ND	NR	<10	<10	NR

(1) Although the data do not show up in our limited data base, they are expected to be present. See Section 5.0

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A - Strontium 89, 90 for soils

TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2

PARAMETER	903 PAD MAXIMUM			903 PAD MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
INDICATORS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
pH (pH units)	..	NR	NR	..	NR	NR
Silica	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	3219	NR	NR	118	NR	NR
INORGANICS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Bicarbonate as CaCO ₃	530	NR	NR	23.1	NR	NR
Carbonate as CaCO ₃	ND	NR	NR	ND	NR	NR
Chloride	819	NR	NR	3.33J	NR	NR
Cyanide	NR	NR	NR	NR	NR	NR
Nitrate as N	NR	NR	NR	NR	NR	NR
Nitrate+Nitrite as N	9.1	NR	NR	<0.02	NR	NR
Sulfate	1157	NR	NR	15.5	NR	NR
RADIONUCLIDES	pCi/l	pCi/l	pCi/g	pCi/l	pCi/l	pCi/g
Americium 241	0.83	NR	NR	<.01	NR	NR
Cesium 137	NR	NR	NR	NR	NR	NR
Gross Alpha	121	NR	NR	<2	NR	NR
Gross Beta	113	NR	NR	<4	NR	NR
Plutonium 239+240	0.52	NR	NR	<0.01	NR	NR
Radium 226	NR	NR	NR	NR	NR	NR
Strontium 90 - A	2.6	NR	NR	<1	NR	NR
Thorium 230+232	NR	NR	NR	NR	NR	NR
Tritium	510	NR	NR	<400	NR	NR
Uranium (total)	62	NR	NR	<1.8	NR	NR
Uranium 233+234	NR	NR	NR	NR	NR	NR
Uranium 235	NR	NR	NR	NR	NR	NR
Uranium 238	NR	NR	NR	NR	NR	NR

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A - Strontium 89, 90 in soils

TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2 (cont.)

PARAMETER	903 PAD MAXIMUM			903 PAD MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
METALS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Aluminum	2.41	NR	NR	<0.0290	NR	NR
Antimony	0.12	NR	NR	0.019	NR	NR
Arsenic	0.04	NR	NR	0.002J	NR	NR
Barium	0.93	NR	NR	0.0191	NR	NR
Beryllium	..	NR	NR	<.005	NR	NR
Boron	NR	NR	NR	NR	NR	NR
Cadmium	0.0058	NR	NR	0.0003J	NR	NR
Calcium	408.44	NR	NR	6.0019	NR	NR
Cesium	..	NR	NR	<0.02	NR	NR
Chromium	0.056	NR	NR	<0.0100	NR	NR
Cobalt	NR	NR	NR	NR	NR	NR
Copper	0.83	NR	NR	<0.0063	NR	NR
Germanium	NR	NR	NR	NR	NR	NR
Iron	1.23	NR	NR	<0.0069	NR	NR
Lead	0.024	NR	NR	0.001J	NR	NR
Lithium	0.16	NR	NR	0.01J	NR	NR
Magnesium	135.71	NR	NR	0.0295	NR	NR
Manganese	0.44	NR	NR	<0.0051	NR	NR
Mercury	0.006	NR	NR	0.0001J	NR	NR
Molybdenum	0.081	NR	NR	<0.022	NR	NR
Nickel	1.41	NR	NR	<0.037	NR	NR
Niobium	NR	NR	NR	NR	NR	NR
Potassium	31	NR	NR	0.7	NR	NR
Rubidium	NR	NR	NR	NR	NR	NR
Selenium	0.37	NR	NR	0.002J	NR	NR
Silver	..	NR	NR	<.0076	NR	NR
Sodium	405.01	NR	NR	6.97	NR	NR
Strontium	7.71	NR	NR	0.21	NR	NR
Tantalum	NR	NR	NR	NR	NR	NR
Tellurium	NR	NR	NR	NR	NR	NR
Thallium	..	NR	NR	<0.01	NR	NR
Tin	NR	NR	NR	NR	NR	NR
Titanium	NR	NR	NR	NR	NR	NR
Tungsten	NR	NR	NR	NR	NR	NR
Vanadium	0.091	NR	NR	<0.016	NR	NR
Zinc	2.77	NR	NR	0.02	NR	NR
Zirconium	NR	NR	NR	NR	NR	NR

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A - Strontium 89, 90 in soils

TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2 (cont.)

PARAMETER	903 PAD MAXIMUM			903 PAD MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
SEMI-VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
Benzo(a)anthracene	NR	NR	NR	NR	NR	NR
Benzo(a)pyrene	NR	NR	NR	NR	NR	NR
Benzo(b)fluoranthene	NR	NR	NR	NR	NR	NR
Benzo(g,h,i)perylene	NR	NR	NR	NR	NR	NR
Benzo(k)fluoranthene	NR	NR	NR	NR	NR	NR
Fluoranthene	NR	NR	NR	NR	NR	NR
Indeno(1,2,3-cd)pyrene	NR	NR	NR	NR	NR	NR
Phenanthrene	NR	NR	NR	NR	NR	NR
Phenol	NR	NR	NR	NR	NR	NR
Pyrene	NR	NR	NR	NR	NR	NR
VOLATILES (1)	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
1,1-Dichloroethane	11	NR	NR	<5	NR	NR
1,1-Dichloroethylene	ND	NR	NR	<5	NR	NR
1,1,1-Trichloroethane	ND	NR	NR	<5	NR	NR
1,1,2-Trichloroethane	ND	NR	NR	<5	NR	NR
1,1,2,2-Tetrachloroethane	ND	NR	NR	<5	NR	NR
1,2-Dichloroethane	ND	NR	NR	<5	NR	NR
2-Butanone	ND	NR	NR	<10	NR	NR
Acetone	ND	NR	NR	<10	NR	NR
Carbon Disulfide	ND	NR	NR	<5	NR	NR
Carbon Tetrachloride	1100J	NR	NR	1J	NR	NR
Chloroform	330	NR	NR	2	NR	NR
Chloromethane	ND	NR	NR	<10	NR	NR
Dichloromethane	ND	NR	NR	<5	NR	NR
Methyl Ketone	NR	NR	NR	NR	NR	NR
Tetrachloroethene	190	NR	NR	4J	NR	NR
Toluene	ND	NR	NR	<5	NR	NR
Trichloroethene	1200	NR	NR	<5	NR	NR
Vinyl Chloride	ND	NR	NR	<10	NR	NR

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TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2 (cont.)

PARAMETER	MOUND AREA MAXIMUM			MOUND AREA MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
INDICATORS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
pH (pH units)	..	NR	NR	..	NR	NR
Silica	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	1813	NR	NR	163	NR	NR
INORGANICS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Bicarbonate as CaCO ₃	642	NR	NR	31	NR	NR
Carbonate as CaCO ₃	ND	NR	NR	ND	NR	NR
Chloride	275	NR	NR	5.7	NR	NR
Cyanide	NR	NR	NR	NR	NR	NR
Nitrate as N	NR	NR	NR	NR	NR	NR
Nitrate+Nitrite as N	9.8	NR	NR	<0.02	NR	NR
Sulfate	1084	NR	NR	3.29J	NR	NR
RADIONUCLIDES	pCi/l	pCi/l	pCi/g	pCi/l	pCi/l	pCi/g
Americium 241	0.11	NR	NR	<.01	NR	NR
Cesium 137	NR	NR	NR	NR	NR	NR
Gross Alpha	39	NR	NR	<2	NR	NR
Gross Beta	37	NR	NR	<4	NR	NR
Plutonium 239+240	0.07	NR	NR	<.01	NR	NR
Radium 226	5	NR	NR	..	NR	NR
Strontium 90 - A	1.2	NR	NR	<1	NR	NR
Thorium 230+232	NR	NR	NR	NR	NR	NR
Tritium	..	NR	NR	..	NR	NR
Uranium (total)	11	NR	NR	<1.8	NR	NR
Uranium 233+234	NR	NR	NR	NR	NR	NR
Uranium 235	NR	NR	NR	NR	NR	NR
Uranium 238	NR	NR	NR	NR	NR	NR

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TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2 (cont.)

PARAMETER	MOUND AREA MAXIMUM			MOUND AREA MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
METALS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Aluminum	2.68	NR	NR	<0.290	NR	NR
Antimony	0.11	NR	NR	<0.02	NR	NR
Arsenic	..	NR	NR	<0.01	NR	NR
Barium	0.19	NR	NR	0.023	NR	NR
Beryllium	..	NR	NR	<0.005	NR	NR
Boron	NR	NR	NR	NR	NR	NR
Cadmium	..	NR	NR	<0.005	NR	NR
Calcium	242.31	NR	NR	12.33	NR	NR
Cesium	..	NR	NR	<0.02	NR	NR
Chromium	0.078	NR	NR	<0.01	NR	NR
Cobalt	NR	NR	NR	NR	NR	NR
Copper	0.42	NR	NR	<0.0063	NR	NR
Germanium	NR	NR	NR	NR	NR	NR
Iron	4.35	NR	NR	<0.0069	NR	NR
Lead	..	NR	NR	<0.005	NR	NR
Lithium	0.2	NR	NR	0.01J	NR	NR
Magnesium	92.2	NR	NR	0.034	NR	NR
Manganese	4.23	NR	NR	<0.0051	NR	NR
Mercury	..	NR	NR	<0.0002	NR	NR
Molybdenum	0.084	NR	NR	<0.022	NR	NR
Nickel	0.69	NR	NR	<0.037	NR	NR
Niobium	NR	NR	NR	NR	NR	NR
Potassium	28	NR	NR	0.5	NR	NR
Rubidium	NR	NR	NR	NR	NR	NR
Selenium	..	NR	NR	<0.005	NR	NR
Silver	..	NR	NR	<0.0076	NR	NR
Sodium	232.1	NR	NR	7.62	NR	NR
Strontium	3.11	NR	NR	0.11	NR	NR
Tantalum	NR	NR	NR	NR	NR	NR
Tellurium	NR	NR	NR	NR	NR	NR
Thallium	..	NR	NR	<0.01	NR	NR
Tin	NR	NR	NR	NR	NR	NR
Titanium	NR	NR	NR	NR	NR	NR
Tungsten	NR	NR	NR	NR	NR	NR
Vanadium	0.24	NR	NR	<0.024	NR	NR
Zinc	2.55	NR	NR	<0.02	NR	NR
Zirconium	NR	NR	NR	NR	NR	NR

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A - Strontium 89, 90 in soils

TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2 (cont.)

PARAMETER	MOUND AREA MAXIMUM			MOUND AREA MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
SEMI-VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
Benzo(a)anthracene	NR	NR	NR	NR	NR	NR
Benzo(a)pyrene	NR	NR	NR	NR	NR	NR
Benzo(b)fluoranthene	NR	NR	NR	NR	NR	NR
Benzo(g,h,i)perylene	NR	NR	NR	NR	NR	NR
Benzo(k)fluoranthene	NR	NR	NR	NR	NR	NR
Fluoranthene	NR	NR	NR	NR	NR	NR
Indeno(1,2,3-cd)pyrene	NR	NR	NR	NR	NR	NR
Phenanthrene	NR	NR	NR	NR	NR	NR
Phenol	NR	NR	NR	NR	NR	NR
Pyrene	NR	NR	NR	NR	NR	NR
VOLATILES (1)	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
1,1-Dichloroethane	59	NR	NR	<5	NR	NR
1,1-Dichloroethylene	13	NR	NR	<5	NR	NR
1,1,1-Trichloroethane	ND	NR	NR	<5	NR	NR
1,1,2-Trichloroethane	ND	NR	NR	<5	NR	NR
1,1,2,2-Tetrachloroethane	ND	NR	NR	<5	NR	NR
1,2-Dichloroethane	ND	NR	NR	<5	NR	NR
2-Butanone	ND	NR	NR	<10	NR	NR
Acetone	ND	NR	NR	<10	NR	NR
Carbon Disulfide	ND	NR	NR	<5	NR	NR
Carbon Tetrachloride	290	NR	NR	<5	NR	NR
Chloroform	ND	NR	NR	<5	NR	NR
Chloromethane	ND	NR	NR	<10	NR	NR
Dichloromethane	ND	NR	NR	<5	NR	NR
Methyl Ketone	ND	NR	NR	NR	NR	NR
Tetrachloroethene	45000	NR	NR	3J	NR	NR
Toluene	ND	NR	NR	<5	NR	NR
Trichloroethene	1800	NR	NR	<5	NR	NR
Vinyl Chloride	520	NR	NR	<10	NR	NR

(1) Although the data do not show up in our limited data base, they are expected to be present. See Section 5.0

B = Present in blank

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A - Strontium 89, 90 in soils

TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2 (cont.)

PARAMETER	EAST TRENCHES MAXIMUM			EAST TRENCHES MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
INDICATORS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
pH (pH units)	..	NR	NR	..	NR	NR
Silica	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	2181	NR	NR	137	NR	NR
INORGANICS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Bicarbonate as CaCO ₃	455	NR	NR	35.3	NR	NR
Carbonate as CaCO ₃	ND	NR	NR	ND	NR	NR
Chloride	947	NR	NR	3.94	NR	NR
Cyanide	NR	NR	NR	NR	NR	NR
Nitrate as N	NR	NR	NR	NR	NR	NR
Nitrate+Nitrite as N	15.45	NR	NR	0.02	NR	NR
Sulfate	820	NR	NR	16.5	NR	NR
RADIONUCLIDES	pCi/l	pCi/l	pCi/g	pCi/l	pCi/l	pCi/g
Americium 241	0.1	NR	NR	<.01	NR	NR
Cesium 137	NR	NR	NR	NR	NR	NR
Gross Alpha	250	NR	NR	<2	NR	NR
Gross Beta	327	NR	NR	<4	NR	NR
Plutonium 239+240	0.18	NR	NR	<.01	NR	NR
Radium 226	NR	NR	NR	NR	NR	NR
Strontium 90 - A	1.4	NR	NR	ND	NR	NR
Thorium 230+232	NR	NR	NR	NR	NR	NR
Tritium	560	NR	NR	<400	NR	NR
Uranium (total)	52	NR	NR	<1.8	NR	NR
Uranium 233+234	NR	NR	NR	NR	NR	NR
Uranium 235	NR	NR	NR	NR	NR	NR
Uranium 238	NR	NR	NR	NR	NR	NR

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A - Strontium 89, 90 in soils

TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2 (cont.)

PARAMETER	EAST TRENCHES			EAST TRENCHES		
	MAXIMUM			MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
METALS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Aluminum	2.63	NR	NR	<0.029	NR	NR
Antimony	0.1	NR	NR	0.006J	NR	NR
Arsenic	0.019	NR	NR	0.004J	NR	NR
Barium	0.32	NR	NR	0.015	NR	NR
Beryllium	..	NR	NR	<0.005	NR	NR
Boron	NR	NR	NR	NR	NR	NR
Cadmium	..	NR	NR	<0.005	NR	NR
Calcium	391.07	NR	NR	12.65	NR	NR
Cesium	NR	NR	NR	<0.02	NR	NR
Chromium	0.12	NR	NR	<0.01	NR	NR
Cobalt	NR	NR	NR	NR	NR	NR
Copper	0.22	NR	NR	<0.0063	NR	NR
Germanium	NR	NR	NR	NR	NR	NR
Iron	2.12	NR	NR	<0.0069	NR	NR
Lead	0.022	NR	NR	<0.005	NR	NR
Lithium	0.22	NR	NR	0.01J	NR	NR
Magnesium	127.67	NR	NR	0.12	NR	NR
Manganese	1.061	NR	NR	<0.0051	NR	NR
Mercury	0.013	NR	NR	<0.0002	NR	NR
Molybdenum	0.13	NR	NR	<0.022	NR	NR
Nickel	0.78	NR	NR	<0.037	NR	NR
Niobium	NR	NR	NR	NR	NR	NR
Potassium	14	NR	NR	0.7	NR	NR
Rubidium	NR	NR	NR	NR	NR	NR
Selenium	0.006	NR	NR	0.002J	NR	NR
Silver	0.13	NR	NR	<0.0076	NR	NR
Sodium	289.22	NR	NR	8.85	NR	NR
Strontium	4.58	NR	NR	0.14	NR	NR
Tantalum	NR	NR	NR	NR	NR	NR
Tellurium	NR	NR	NR	NR	NR	NR
Thallium	..	NR	NR	<0.01	NR	NR
Tin	NR	NR	NR	NR	NR	NR
Titanium	NR	NR	NR	NR	NR	NR
Tungsten	NR	NR	NR	NR	NR	NR
Vanadium	0.11	NR	NR	<0.02	NR	NR
Zinc	0.98	NR	NR	<0.02	NR	NR
Zirconium	NR	NR	NR	NR	NR	NR

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A - Strontium 89, 90 in soils

TABLE A-2: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 2 (cont.)

PARAMETER	EAST TRENCHES MAXIMUM			EAST TRENCHES MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
SEMI-VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
Benzo(a)anthracene	NR	NR	NR	NR	NR	NR
Benzo(a)pyrene	NR	NR	NR	NR	NR	NR
Benzo(b)fluoranthene	NR	NR	NR	NR	NR	NR
Benzo(g,h,i)perylene	NR	NR	NR	NR	NR	NR
Benzo(k)fluoranthene	NR	NR	NR	NR	NR	NR
Fluoranthene	NR	NR	NR	NR	NR	NR
Indeno(1,2,3-cd)pyrene	NR	NR	NR	NR	NR	NR
Phenanthrene	NR	NR	NR	NR	NR	NR
Phenol	NR	NR	NR	NR	NR	NR
Pyrene	NR	NR	NR	NR	NR	NR
VOLATILES (1)	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
1,1-Dichloroethane	32	NR	<5	<5	NR	ND
1,1-Dichloroethylene	ND	NR	ND	<5	NR	ND
1,1,1-Trichloroethane	63	NR	250	<5	NR	ND
1,1,2-Trichloroethane	ND	NR	ND	<5	NR	ND
1,1,2,2-Tetrachloroethane	ND	NR	ND	<5	NR	ND
1,2-Dichloroethane	ND	NR	ND	<5	NR	ND
2-Butanone	ND	NR	ND	<10	NR	ND
Acetone	ND	NR	ND	<10	NR	ND
Carbon Disulfide	ND	NR	ND	<5	NR	ND
Carbon Tetrachloride	1100	NR	ND	<5	NR	ND
Chloroform	290E	NR	ND	3J	NR	ND
Chloromethane	ND	NR	ND	<10	NR	ND
Dichloromethane	ND	NR	ND	<5	NR	ND
Methyl Ketone	NR	NR	NR	NR	NR	NR
Tetrachloroethene	350E	NR	10000	3J	NR	ND
Toluene	ND	NR	ND	<5	NR	ND
Trichloroethene	49000	NR	16000	3J	NR	ND
Vinyl Chloride	ND	NR	ND	<10	NR	ND

(1) Although the data do not show up in our limited data base, they are expected to be present. See Section 5.0

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A - Strontium 89, 90 in soils

TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 4 (cont.)

PARAMETER	SOLAR PONDS MAXIMUM			SOLAR PONDS MINIMUM		
	GROUND WATER	SURFACE (1) WATER	SOILS	GROUND WATER	SURFACE (1) WATER	SOILS
INDICATORS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
pH (pH units)	..	12.5	NR	..	7.3	NR
Silica	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	16776	175800	NR	..	93859	NR
INORGANICS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Bicarbonate as CaCO ₃	682	..	NR	..	..	NR
Carbonate as CaCO ₃	ND	ND	NR	ND	ND	NR
Chloride	336	..	NR	ND	ND	NR
Cyanide	ND	1.9	NR	ND	ND	NR
Nitrate as N	2200	ND	1480	ND	ND	ND
Nitrate+Nitrite as N	NR	NR	NR	NR	NR	NR
Phosphorous	0.2	ND	NR	ND	0.014	NR
Sulfate	500	..	NR	ND	ND	NR
RADIONUCLIDES	pCi/l	pCi/l	pCi/g	pCi/l	pCi/l	pCi/g
Americium 241	NR	13000	2.2	NR	ND	ND
Cesium 137	NR	NR	NR	NR	NR	NR
Gross Alpha	NR	80000	NR	NR	4	NR
Gross Beta	NR	40000	NR	NR	2	NR
Plutonium 239+240	NR	2100	18	NR	ND	ND
Radium 226	NR	NR	NR	NR	NR	NR
Strontium 90 - A	NR	NR	NR	NR	NR	NR
Thorium 230+232	NR	NR	NR	NR	NR	NR
Tritium	NR	6400	NR	NR	0	NR
Uranium (total)	NR	40000	NR	NR	0.69	NR
Uranium 233+234	NR	20000	4	NR	50	ND
Uranium 235	NR	NR	NR	NR	NR	NR
Uranium 238	NR	28000	2.8	NR	21000	ND

(1) Data is for liquids in equilibrium with sludge from solar ponds

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A - Strontium 89, 90 in soils

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TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 4 (cont.)

PARAMETER	SOLAR PONDS MAXIMUM			SOLAR PONDS MINIMUM		
	GROUND WATER	SURFACE (1) WATER	SOILS	GROUND WATER	SURFACE (1) WATER	SOILS
METALS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Aluminum	NR	2.64	30899	NR	<0.0028	ND
Antimony	0.062	<.035	NR	ND	<0.028	ND
Arsenic	NR	0.15	64	NR	<0.01	ND
Barium	0.39	0.22	345	ND	<1.0	ND
Beryllium	NR	0.1	103.13	NR	0.002	ND
Boron	NR	0.67	NR	NR	0.071	NR
Cadmium	NR	0.15	345.06	NR	<0.01	ND
Calcium	826.67	290	50000	ND	2.9	ND
Cesium	NR	0.35	NR	NR	<0.28	NR
Chromium	NR	16.7	780	NR	<0.05	ND
Cobalt	NR	0.5	NR	NR	<0.014	NR
Copper	NR	1.8	58	NR	<0.014	ND
Germanium	NR	<.018	NR	NR	<0.014	NR
Iron	NR	8	29505	NR	<0.03	ND
Lead	NR	0.0035	NR	NR	<0.0028	NR
Lithium	NR	6	NR	NR	0.052	NR
Magnesium	253.8	120	6730	ND	3.9	ND
Manganese	1.71	0.115	1258	ND	<0.0028	ND
Mercury	0.0007	<.002	NR	ND	<0.002	NR
Molybdenum	0.19	0.037	NR	ND	<0.0028	NR
Nickel	0.28	2	543	ND	<0.028	ND
Niobium	NR	<.18	NR	NR	<0.14	NR
Potassium	260	14300	5200	ND	30	ND
Rubidium	NR	0.035	NR	NR	<0.28	NR
Selenium	0.18	0.024	NR	ND	<0.01	NR
Silver	NR	0.082	NR	NR	<0.0028	NR
Sodium	2535.89	42900	NR	ND	67	NR
Strontium	7.66	3.5	NR	ND	0.14	NR
Tantalum	NR	<.035	NR	NR	<0.028	NR
Tellurium	NR	<.35	NR	NR	<0.28	NR
Thallium	NR	ND	12750.58	NR	<0.014	ND
Tin	NR	13	NR	NR	<0.028	NR
Titanium	NR	<.018	NR	NR	<0.014	NR
Tungsten	NR	<1.8	NR	NR	<1.4	NR
Vanadium	NR	0.2	80	NR	<0.028	ND
Zinc	0.96	0.78	116	ND	<1.4	ND
Zirconium	NR	<.035	NR	NR	0.0041	NR

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A - Strontium 89, 90 in soils

TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 4 (cont.)

PARAMETER	SOLAR PONDS MAXIMUM			SOLAR PONDS MINIMUM		
	GROUND WATER	SURFACE (1) WATER	SOILS	GROUND WATER	SURFACE (1) WATER	SOILS
SEMI-VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
Anthracene	NR	NR	NR	NR	NR	NR
Benzo(a)Anthracene	NR	NR	NR	NR	NR	NR
Benzo(a)pyrene	NR	NR	NR	NR	NR	NR
Benzo(b)fluoranthene	NR	NR	NR	NR	NR	NR
Benzo(g,h,i)perylene	NR	NR	NR	NR	NR	NR
Benzo(k)fluoranthene	NR	NR	NR	NR	NR	NR
Fluoranthene	NR	NR	NR	NR	NR	NR
Indeno(1,2,3-cd)pyrene	NR	NR	NR	NR	NR	NR
Phenanthrene	NR	NR	NR	NR	NR	NR
Phenols	NR	0.046	NR	NR	0.003	NR
Pyrene	NR	NR	NR	NR	NR	NR
VOLATILES (2)	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
1,1-Dichloroethane	NR	ND	ND	NR	ND	ND
1,1-Dichloroethylene	NR	ND	ND	NR	ND	ND
1,1,1-Trichloroethane	NR	ND	ND	NR	ND	ND
1,1,2-Trichloroethane	NR	ND	ND	NR	ND	ND
1,1,2,2-Tetrachloroethane	NR	ND	ND	NR	ND	ND
1,2-Dichloroethane	NR	ND	ND	NR	ND	ND
2-Butanone	NR	ND	NR	NR	ND	NR
Acetone	NR	ND	110	NR	ND	ND
Carbon Disulfide	NR	ND	ND	NR	ND	ND
Carbon Tetrachloride	NR	ND	ND	NR	ND	ND
Chloroform	NR	ND	ND	NR	ND	ND
Chloromethane	NR	ND	52	NR	ND	ND
Dichloromethane	NR	ND	29.3	NR	ND	ND
Methyl Ketone	NR	NR	NR	NR	NR	NR
Tetrachloroethene	NR	ND	ND	NR	ND	ND
Toluene	NR	ND	ND	NR	ND	ND
Trichloroethene	NR	ND	ND	NR	ND	ND
Vinyl Chloride	NR	ND	ND	NR	ND	ND

(1) Data is for liquids in equilibrium with sludge from solar ponds

(2) Although the data do not show up in our limited data base, they are expected to be present. See Section 5.0

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A - Strontium 89, 90 in soils

TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 7

PARAMETER	PRESENT LANDFILL MAXIMUM			PRESENT LANDFILL MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
INDICATORS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
pH (pH units)	..	..	NR	..	..	NR
Silica	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	7363	1082	NR	..	533	NR
INORGANICS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Bicarbonate as CaCO ₃	220	402	NR	..	190	NR
Carbonate as CaCO ₃	ND	ND	NR	ND	ND	NR
Chloride	826	124	37	..	91	12
Cyanide	ND	ND	0.13	ND	ND	0.005
Nitrate as N	NR	NR	NR	NR	NR	NR
Nitrate+Nitrite as N	3.22	<.2	113.7	..	..	46.9
Phosphorous	NR	NR	NR	NR	NR	NR
Sulfate	4600	52	744	..	8	91
RADIONUCLIDES	pCi/l	pCi/l	pCi/g	pCi/l	pCi/l	pCi/g
Americium 241	0.69	0.704	0.42	..	0.12	0.01
Cesium 137	NR	NR	NR	NR	NR	NR
Gross Alpha	249	23	26	..	0	16
Gross Beta	250	27	32	..	5	17
Plutonium 239+240	4.7	..	1.9	..	..	0
Radium 226	NR	NR	NR	NR	NR	NR
Strontium 90 - A	9.3	..	..	..	..	..
Thorium 230+232	NR	NR	NR	NR	NR	NR
Tritium	20000	440	0.17	..	110	0.12
Uranium (total)	NR	NR	NR	NR	NR	NR
Uranium 233+234	40	1.1	0.95	..	0	0.57
Uranium 235	..	2.6
Uranium 238	..	9.8	1	..	0	0.33

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A - Strontium 89, 90 in soils

TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 7 (cont.)

PARAMETER	PRESENT LANDFILL MAXIMUM			PRESENT LANDFILL MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
METALS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Aluminum	36.6	0.7	10500	ND	0.12	9.7
Antimony	..	<.05	..	ND	ND	ND
Arsenic	0.015	<0.01	1.3	ND	ND	0.1
Barium	0.34	0.58	152	ND	0.1	57
Beryllium	0.26	<.005	2.3	ND	ND	0.88
Boron	NR	NR	NR	NR	NR	NR
Cadmium	0.001	<.005	NR	ND	ND	ND
Calcium	473.09	100	5890	ND	40	710
Cesium	NR	<.2	NR	NR	NR	NR
Chromium	0.19	0.019	16	ND	0.011	7
Cobalt	0.031	<.05	8	ND	ND	6.9
Copper	0.08	<.02	19	ND	ND	13
Germanium	NR	NR	NR	NR	NR	NR
Iron	28.2	2.3	30300	ND	0.03	12500
Lead	0.025	<.005	14	ND	NR	7.9
Lithium	0.013	NR	NR	ND	NR	NR
Magnesium	291.73	75	2570	ND	21	250
Manganese	2.13	0.42	533	ND	0.06	200
Mercury	0.0016	..	0.5	ND	ND	0.18
Molybdenum	0.13	<0.1	11	ND	ND	<8.8
Nickel	1.4	<.04	15	ND	ND	12
Niobium	NR	NR	NR	NR	NR	NR
Potassium	41.1	68	4450	ND	9	ND
Rubidium	NR	NR	NR	NR	NR	NR
Selenium	0.089	<.005	0.13	NR	NR	<0.1
Silver	0.019	<.01	2.2	ND	ND	<0.88
Sodium	4447	226	256	ND	75	170
Strontium	9.47	1.05	57	ND	0.4	14
Tantalum	NR	NR	NR	NR	NR	NR
Tellurium	NR	NR	NR	NR	NR	NR
Thallium	..	<.01	90	ND	ND	<1.1
Tin	NR	NR	NR	NR	NR	NR
Titanium	NR	NR	NR	NR	NR	NR
Tungsten	NR	NR	NR	NR	NR	NR
Vanadium	0.1	<.024	42	ND	ND	32
Zinc	0.58	..	71	ND	ND	61
Zirconium	NR	NR	NR	NR	NR	NR

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A - Strontium 89, 90 in soils

TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 7 (cont.)

PARAMETER	PRESENT LANDFILL MAXIMUM			PRESENT LANDFILL MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
SEMI-VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
Anthracene	NR	NR	400	NR	NR	<390
Benzo(a)Anthracene	NR	NR	520	NR	NR	<390
Benzo(a)pyrene	NR	NR	560	NR	NR	<390
Benzo(b)fluoranthene	NR	NR	880	NR	NR	<390
Benzo(g,h,i)perylene	NR	NR	680	NR	NR	<390
Benzo(k)fluoranthene	NR	NR	880	NR	NR	<390
Fluoranthene	NR	NR	1600	NR	NR	<390
Indeno(1,2,3-cd)pyrene	NR	NR	560	NR	NR	<390
Phenanthrene	NR	NR	1400	NR	NR	<390
Phenols	NR	NR	ND	NR	NR	<390
Pyrene	NR	NR	1300	NR	NR	<390
VOLATILES (1)	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
1,1-Dichloroethane	NR	NR	NR	NR	NR	ND
1,1-Dichloroethylene	NR	NR	NR	NR	NR	ND
1,1,1-Trichloroethane	NR	NR	NR	NR	NR	ND
1,1,2-Trichloroethane	NR	NR	NR	NR	NR	ND
1,1,2,2-Tetrachloroethane	NR	NR	NR	NR	NR	ND
1,2-Dichloroethane	NR	NR	NR	NR	NR	ND
2-Butanone	NR	NR	19	NR	NR	<10
Acetone	NR	NR	240	NR	NR	106
Carbon Disulfide	NR	NR	ND	NR	NR	ND
Carbon Tetrachloride	NR	NR	ND	NR	NR	ND
Chloroform	NR	NR	ND	NR	NR	ND
Chloromethane	NR	NR	ND	NR	NR	ND
Dichloromethane	NR	NR	90	NR	NR	1J
Methyl Ketone	NR	NR	NR	NR	NR	NR
Tetrachloroethene	NR	NR	NR	NR	NR	NR
Toluene	NR	NR	NR	NR	NR	NR
Trichloroethene	NR	NR	NR	NR	NR	NR
Vinyl Chloride	NR	NR	NR	NR	NR	NR

(1) Although the data do not show up in our limited data base, they are expected to be present. See Section 5.0

B = Present in blank

J = Present below quantitation limit

E = Estimated

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NR = Not reported, presumably not tested for based on reference documents

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A - Strontium 89, 90 in soils

TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 11 (cont.)

PARAMETER	WEST SPRAY FIELD MAXIMUM			WEST SPRAY FIELD MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
INDICATORS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
pH (pH units)	10.6	..	NR	5.5	..	NR
Silica	NR	5.6	NR	NR	ND	NR
Total Dissolved Solids	500	NR	NR	<167	NR	NR
INORGANICS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Bicarbonate as CaCO ₃	153	NR	NR	<80	NR	NR
Carbonate as CaCO ₃	120	NR	NR	<5	NR	NR
Chloride	444	NR	NR	<19	NR	NR
Cyanide	NR	NR	NR	NR	NR	NR
Nitrate as N	32.4	1367	420	<1.5	..	30
Nitrate+Nitrite as N	NR	NR	NR	NR	NR	NR
Phosphorous	NR	NR	NR	NR	NR	NR
Sulfate	1340	NR	NR	<27	NR	NR
RADIONUCLIDES	pCi/l	pCi/l	pCi/g	pCi/l	pCi/l	pCi/g
Americium 241	..	0.08	0.28	<0.048	..	..
Cesium 137	NR	NR	NR	NR	NR	NR
Gross Alpha	620	323	75	<57	..	20
Gross Beta	1200	163	56	<65	..	29
Plutonium 239+240	4.7	0.84	0.59	..	..	0.08
Radium 226	NR	NR	NR	NR	NR	NR
Strontium 90 - A	5.04	NR	NR	<3.32	NR	NR
Thorium 230+232	NR	NR	NR	NR	NR	NR
Tritium	2218	3400	0.54	<593	..	0.08
Uranium (total)	NR	NR	NR	NR	NR	NR
Uranium 233+234	15	..	1.4	<1.5	..	0.59
Uranium 235	4	NR	NR	..	NR	NR
Uranium 238	16	..	1.2	<2.2	..	0.61

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A - Strontium 89, 90 in soils

TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 11 (cont.)

PARAMETER	WEST SPRAY FIELD MAXIMUM			WEST SPRAY FIELD MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
METALS	mg/l	mg/l	mg/kg	mg/l	mg/l	mg/kg
Aluminum	1.86	2	10600	<0.029	ND	7010
Antimony	NR	NR	..	NR	NR	<41
Arsenic	NR	NR	9.2	NR	NR	6.1
Barium	0.52	0.22	..	<0.071	ND	<135
Beryllium	0.08	NR	..	<0.005	NR	<3.4
Boron	NR	0.67	NR	NR	ND	NR
Cadmium	..	..	..	<0.005	ND	<3.4
Calcium	54.87	410	2240	<34	ND	1070
Cesium	0.36	0.041	NR	<0.02	ND	NR
Chromium	0.14	0.009	14	<0.01	ND	6.8
Cobalt	0.1	NR	25	<0.02	NR	<12
Copper	0.038	0.37	11	<0.012	ND	6.3
Germanium	NR	NR	NR	NR	NR	NR
Iron	1.3	0.74	12500	<0.011	ND	9160
Lead	0.054	0.0035	63	<0.01	ND	14
Lithium	NR	3.5	NR	NR	ND	NR
Magnesium	8.86	100	..	<5.9	ND	922
Manganese	0.37	0.081	337	<0.026	ND	206
Mercury	0.003	0.5	1490	<0.0002	ND	0.13
Molybdenum	0.51	0.037	NR	<0.022	ND	NR
Nickel	0.077	0.15	..	<0.037	ND	19
Niobium	NR	NR	NR	NR	NR	NR
Potassium	..	..	..	<0.8	ND	120
Rubidium	NR	NR	NR	NR	NR	NR
Selenium	0.009	0.02	NR	<0.005	NR	NR
Silver	NR	0.082	..	NR	ND	<5
Sodium	620	36.04	217	<13	ND	68
Strontium	0.46	3.5	NR	<0.01	ND	NR
Tantalum	NR	NR	NR	NR	NR	NR
Tellurium	NR	NR	NR	NR	NR	NR
Thallium	0.019	NR	..	<0.01	NR	<6.8
Tin	NR	NR	..	NR	NR	<41
Titanium	NR	NR	NR	NR	NR	NR
Tungsten	NR	NR	NR	NR	NR	NR
Vanadium	0.85	0.0081	38	<0.024	ND	<30
Zinc	1.77	0.08	52	<0.04	ND	24
Zirconium	NR	0.0041	NR	NR	ND	NR

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A - Strontium 89, 90 in soils

TABLE A-3: ANALYTE CONCENTRATIONS FOR OPERABLE UNIT 11 (cont.)

PARAMETER	WEST SPRAY FIELD MAXIMUM			WEST SPRAY FIELD MINIMUM		
	GROUND WATER	SURFACE WATER	SOILS	GROUND WATER	SURFACE WATER	SOILS
SEMI-VOLATILES	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
Anthracene	NR	NR	NR	NR	NR	NR
Benzo(a)Anthracene	NR	NR	NR	NR	NR	NR
Benzo(a)pyrene	NR	NR	NR	NR	NR	NR
Benzo(b)fluoranthene	NR	NR	NR	NR	NR	NR
Benzo(g,h,i)perylene	NR	NR	NR	NR	NR	NR
Benzo(k)fluoranthene	NR	NR	NR	NR	NR	NR
Fluoranthene	NR	NR	NR	NR	NR	NR
Indeno(1,2,3-cd)pyrene	NR	NR	NR	NR	NR	NR
Phenanthrene	NR	NR	NR	NR	NR	NR
Phenols	NR	NR	0.5	NR	NR	ND
Pyrene	NR	NR	NR	NR	NR	NR
VOLATILES (1)	ug/l	ug/l	ug/kg	ug/l	ug/l	ug/kg
1,1-Dichloroethane	NR	ND	ND	NR	ND	ND
1,1-Dichloroethylene	NR	ND	ND	NR	ND	ND
1,1,1-Trichloroethane	NR	ND	2J	NR	ND	ND
1,1,2-Trichloroethane	NR	ND	2J	NR	ND	ND
1,1,2,2-Tetrachloroethane	NR	ND	ND	NR	ND	ND
1,2-Dichloroethane	NR	ND	ND	NR	ND	ND
2-Butanone	NR	NR	NR	NR	NR	NR
Acetone	NR	ND	260	NR	ND	14B
Carbon Disulfide	NR	ND	ND	NR	ND	ND
Carbon Tetrachloride	NR	ND	ND	NR	ND	ND
Chloroform	NR	ND	ND	NR	ND	ND
Chloromethane	NR	35B	70B	NR	ND	29B
Dichloromethane	NR	ND	ND	NR	ND	ND
Methyl Ketone	NR	NR	61	NR	NR	NR
Tetrachloroethene	NR	ND	23	NR	ND	ND
Toluene	NR	ND	43	NR	ND	ND
Trichloroethene	NR	ND	ND	NR	ND	ND
Vinyl Chloride	NR	ND	ND	NR	ND	ND

(1) Although the data do not show up in our limited data base, they are expected to be present. See Section 5.0

B = Present in blank

J = Present below quantitation limit

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A - Strontium 89, 90 in soils

APPENDIX B
POTENTIAL ARARS FOR THE SITEWIDE
TREATABILITY STUDIES PROGRAM

APPENDIX B: POTENTIAL ARARs FOR SITEWIDE TREATABILITY STUDIES PROGRAM

Parameter	Type	SDWA Maximum Contaminant Level (e)(1)(g)	SDWA Maximum Contaminant Level Goal (e)	EPA Criteria For Protection of Aquatic Life Acute/Chronic (a)(g)	CDH Surface Water Quality Standard (5)(c)(d)	CDH Groundwater Quality Standard (1)(b)	CDH Surface Water (30-day) Agricultural Standard (d)	CDH Groundwater Agricultural Standard (b)	RCRA Subpart F Concentration Limit (40CFR264.94) (g)
pH	Indicator	6.5-8.5		6.5-9.0	6.5-9.0	6.5-8.5 h		6.5-8.5 g	
Silica	Indicator								
Total Dissolved Solids	Indicator	500 mg/l				400 mg/l (2)		400 mg/l (2)	
Bicarbonate as CaCO ₃	Inorganic								
Carbonate as CaCO ₃	Inorganic								
Chloride	Inorganic	250 mg/l				250 mg/l h			
Cyanide	Inorganic			22/ 5.2 ug/l	0.005 mg/l	0.20 mg/l h			
N as Nitrate	Inorganic	10 mg/l			10.0 mg/l	10.0 mg/l h			
N as Nitrate+Nitrite	Inorganic								
Potassium	Inorganic								
Sulfate	Inorganic	250 mg/l				250 mg/l h		100 mg/l	
Aluminum	Inorganic								
Antimony	Metal			9/ 1.6 mg/l	.05 mg/l		0.1 mg/l	5.0 mg/l	
Arsenic	Metal	0.05 mg/l				0.05 mg/l h		0.1 mg/l	0.05 mg/l
Arsenic III	Metal			0.36/ 0.19 mg/l					
Arsenic V	Metal			0.8/ 0.048 mg/l					
Barium	Metal	1.0 mg/l				1.0 mg/l h	0.1 mg/l	0.1 mg/l	1 mg/l
Beryllium	Metal			0.13/ 0.0053 mg/l					
Boron	Metal								
Cadmium	Metal	0.01 mg/l		3.9/ 1.1 ug/l (3)	0.75 mg/l	0.01 mg/l h	0.01 mg/l	0.75 mg/l	0.01 mg/l
Calcium	Metal				TVS			0.01 mg/l	
Cesium	Metal								
Chromium	Metal	0.05 mg/l				0.05 mg/l h		0.1 mg/l	0.05 mg/l
Chromium III	Metal			1.7/ 0.2 mg/l	0.05 mg/l		0.1 mg/l		
Chromium VI	Metal			0.016/ 0.011 mg/l	TVS		0.1 mg/l		
Cobalt	Metal								
Copper	Metal	1 mg/l		18/12 ug/l	TVS	1.0 mg/l h	0.2 mg/l	0.05 mg/l	
Iron	Metal	0.3 mg/l		1.0 mg/l	0.3 mg/l (6)	0.3 mg/l h		0.2 mg/l	
Lead	Metal	0.05 mg/l		82/ 3.2 ug/l (3)	TVS	0.05 mg/l h	0.1 mg/l	5 mg/l	
Lithium	Metal							0.1 mg/l	0.05 mg/l
Magnesium	Metal							2.5 mg/l	

APPENDIX B: POTENTIAL ARARs FOR SITEWIDE TREATABILITY STUDIES PROGRAM (cont.)

Parameter	Type	SDWA Maximum Contaminant Level (e)(1)(g)	SDWA Maximum Contaminant Level Goal (e)	EPA Criteria For Protection of Aquatic Life Acute/Chronic (a)(g)	CDH Surface Water Quality Standard (5)(c)(d)	CDH Groundwater Quality Standard (1)(b)	CDH Surface Water (30-day) Agricultural Standard (d)	CDH Groundwater Agricultural Standard (b)	RCRA Subpart F Concentration Limit (40CFR264.94) (g)
Manganese	Metal	0.05 mg/l			0.05 mg/l (6)	0.05 mg/l h	0.2 mg/l	0.2 mg/l	
Mercury	Metal	0.002 mg/l		2.4/ 0.012 ug/l	0.01 ug/l	0.002 mg/l h	0.01 mg/l	0.01 mg/l	0.002 mg/l
Molybdenum	Metal								
Nickel	Metal			1.4/ 0.16 mg/l	TVS		0.2 mg/l	0.1 mg/l	
Niobium	Metal							0.2 mg/l	
Rubidium	Metal								
Selenium	Metal	0.01 mg/l		0.26/ 0.035 mg/l	0.01 mg/l	0.01 mg/l h	0.02 mg/l	0.02 mg/l	0.01 mg/l
Silver	Metal	0.05 mg/l		4.1/ 0.12 ug/l	TVS	0.05 mg/l h			0.05 mg/l
Sodium	Metal								
Strontium	Metal								
Tantalum	Metal								
Tellurium	Metal								
Thallium	Metal			1.4/ 0.04 mg/l (4)					
Tin	Metal								
Titanium	Metal								
Tungsten	Metal								
Vanadium	Metal								
Zinc	Metal	5.0 mg/l		0.12/ 0.11 mg/l (3)	TVS	5 mg/l h	2.0 mg/l	0.1 mg/l 2.0 mg/l	
Zirconium	Metal								
Americium 241	Radionuclide				0.05 pCi/l				
Cesium 137 (134)	Radionuclide				(80) pCi/l				
Gross Alpha	Radionuclide	15 pCi/l			7/ 11 pCi/l (8)				
Gross Beta	Radionuclide	4 mrem/yr			5/ 19 pCi/l (8)				
Plutonium 238 + 239 + 240	Radionuclide				15 pCi/l				
Radium 226(+ 228)	Radionuclide	5 pCi/l			5 pCi/l				
Strontium 89 + 90	Radionuclide				8 pCi/l				
Thorium 230 + 232	Radionuclide				60 pCi/l				
Tritium	Radionuclide				500 pCi/l				
Uranium 233 + 234	Radionuclide								
Uranium 235	Radionuclide								
Uranium 238	Radionuclide								
Uranium (total)	Radionuclide				5/ 10 pCi/l (8)				

APPENDIX B: POTENTIAL ARARs FOR SITEWIDE TREATABILITY STUDIES PROGRAM (cont.)

Parameter	Type	SDWA Maximum Contaminant Level (e)(1)(g)	SDWA Maximum Contaminant Level Goal (e)	EPA Criteria For Protection of Aquatic Life Acute/Chronic (e)(g)	CDH Surface Water Quality Standard (5)(c)(d)	CDH Groundwater Quality Standard (1)(b)	CDH Surface Water (30-day) Agricultural Standard (d)	CDH Groundwater Agricultural Standard (b)	RCRA Subpart F Concentration Limit (40CFR264.94) (g)
Benzo(a)anthracene	Semi-Volatile				2.8 mg/l (5)				
Benzo(a)pyrene	Semi-Volatile				2.8 mg/l (5)				
Benzo(b)fluoranthene	Semi-Volatile				2.8 mg/l (5)				
Benzo(g,h,i)perylene	Semi-Volatile				2.8 mg/l (5)				
Benzo(k)fluoranthene	Semi-Volatile				2.8 mg/l (5)				
Fluoranthene	Semi-Volatile			3.9 mg/l (4)	2.8 mg/l (5)				
Phenanthrene	Semi-Volatile				2.8 mg/l (5)				
Phenol	Semi-Volatile			10.2/ 2.56 mg/l (4)	2.8 mg/l (5)	0.001 mg/l h			
Pyrene	Semi-Volatile				(9)				
1,1-Dichloroethane	Volatile			20/ 118 mg/l (4)	(9)				
1,1-Dichloroethylene	Volatile	7 ug/l	7 ug/l	11.67/ ug/l (4)	(9)	7 ug/l s			
1,1,1-Trichloroethane	Volatile	200 ug/l	200 ug/l		(9)	200 ug/l s			
1,1,2-Trichloroethane	Volatile			/ 9.4 mg/l (4)	0.6 ug/l	28 ug/l s			
1,1,2,2-Tetrachloroethane	Volatile			9.32/ 2.4 mg/l (4)	0.17 ug/l				
1,2-Dichloroethane	Volatile	5 ug/l	0 ug/l (10)	118/ 20 mg/l (4)	(9)	5 ug/l s			
2-Butanone	Volatile		0 ug/l (10)		(9)				
Acetone	Volatile				(9)				
Carbon Disulfide	Volatile				(9)				
Carbon Tetrachloride	Volatile	5 ug/l		35.2 / mg/l (4)	(9)	5 ug/l s			
Chloroform	Volatile	Tot THM <100 ug/l(11)		28.9/ 1.24 mg/l (4)	(9)				
Dichloromethane	Volatile				(9)				
Indeno(1,2,3-cd)pyrene	Volatile				(9)				
Methyl Ketone	Volatile				(9)				
Tetrachloroethene	Volatile			5.28/ 0.84 mg/l (4)	(9)	10 ug/l s			
Toluene	Volatile			17.5/ mg/l (4)	(9)	2420 ug/l s			
Trichloroethene	Volatile	5 ug/l	0 ug/l (10)	45/ 21.9 mg/l	(9)	5 ug/l s			
Vinyl Chloride	Volatile	2 ug/l	0 ug/l (10)	2 ug/l	(9)	2 ug/l s			

(1) s = statewide standard; h = human health standard or secondary drinking water standard; the human health numeric standards (3.11.5.B) pertain to classified groundwater areas; the narrative standards (3.11.5.A) are applicable statewide

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- (2) TDS standard: 400 mg/l or 1.25 times the background level, whichever is least restrictive
 - (3) hardness dependent criteria
 - (4) criteria not developed; value presented is lowest observed effects level (LOEL)
 - (5) TVS = Table Value Standard (hardness dependent): Table III in (d)
 - (6) lowest value given: dissolved or total recoverable
 - (7) value given for polynuclear aromatic hydrocarbons (PAHs)
 - (8) specific standards given for Woman Creek/ Walnut Creek
 - (9) In the absence of specific, numeric standards for non-naturally occurring organics, the narrative standard is interpreted as zero with enforcement based on practical quantification levels (PQLs) as defined by WQCD or EPA
 - (10) recommended MCL
 - (11) total trihalomethanes
 - (a) EPA, Quality Criteria for Protection of Aquatic Life, 1986
 - (b) CDH, Water Quality Control Commission, The Basic Standards for Ground Water, 3.11.0 (1/5/1987 amended 8/17/89)
 - (c) CDH, Water Quality Control Commission, Classifications and Numeric Standards for S. Platte River Basin, Laramie River Basin, Republican River Basin, Smoky Hill River basin (4CCR 1002-8) 4/6/1981; amended 2/5/1990
 - (d) CDH, Water Quality Control Commission, Water Quality Standards and Stream Classification (1/15/1974 amended 9/30/1988)
 - (e) EPA National Primary Drinking Water Regulations, 40 CFR 141 (12/24/75 amended 7/17/89)
 - (f) EPA National Secondary Drinking Water Regulations, 40 CFR 143 (7/19/1979 amended 9/26/1988)
 - (g) CERCLA Compliance with Other Laws Manual, EPA/540/G-89/006, August 1988

APPENDIX C
TECHNOLOGY DATA SHEETS

TECHNOLOGY DATA SHEET

AIR STRIPPING

Description

Air stripping is a proven technology for removing volatile and semivolatile organic contaminants from water. The process involves transferring liquid phase contaminants to the vapor phase (EPA, 1986a). This is accomplished by applying liquid to the top of an air stripping column (tower), countercurrent to upflowing air. The tower is filled with packing that provides a large surface area to enable efficient mass transfer between the two phases. Contaminants are stripped from water to air depending on their relative volatility. Strippability is generally evaluated based on the Henry's Law constants of the compounds to be removed. The water concentrations of each compound decrease as they pass through the column. The removal efficiencies can be increased by increasing the height of the packed tower or the number of air stripping units. Process efficiency is also dependent on the air:water ratio; a higher air:water ratio will improve removal efficiencies.

Since air stripping involves transfer of contaminants to the gas phase, air emission treatment is generally required. Vapor phase activated carbon systems are most commonly used for this purpose, but other alternatives, such as oxidation and incineration, exist. The vapor phase treatment unit may be costly.

Applications

The applicability of air stripping can be determined from the Henry's Law constants of the compounds to be removed. Generally, compounds with Henry's Law constants higher than that for chloroform ($H = 2.9 \times 10^{-3} \text{ atm}^3/\text{mole}$) are considered suitable for air stripping, but less volatile compounds may be removed at high air:water ratios. Low molecular weight halogenated organics are easily removed in this process, while it is somewhat less efficient for removal of semivolatile aromatics such as benzene. Two of the major volatile organic

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contaminants in Rocky Flats water, trichloroethylene (TCE) and vinyl chloride, have Henry's constants higher than that for chloroform, and the value for tetrachloroethylene is insignificantly different than that for chloroform (Kavanaugh and Trussel, 1980).

Studies by Fang and Khor (1989) show that removal efficiencies as high as 99.8 percent can be achieved by air stripping of volatile organics, such as vinyl chloride, carbon tetrachloride, TCE, 1,1-dichloroethane, toluene, chloroform, benzene, and xylene. High removal efficiencies for removal of these compounds is also reported by the American Water Works Association.¹

Advantages and Disadvantages

The major advantages of air stripping are ease of operation and high removal efficiencies for volatiles. Disadvantages of this technology are that efficient treatment is limited to volatiles, and transfer of contaminants to the vapor phase generally makes costly emission treatment necessary.

¹ Occurrence and Removal of Volatile Organics Compounds from Drinking Water. AWWA Research Foundation.

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TECHNOLOGY DATA SHEET

STEAM STRIPPING

Description

Steam stripping involves injection of steam into a solution to volatilize the organic compounds in the solution. It can be operated as a batch or continuous process.

The batch process involves a batch still, an overhead vapor line, a condenser, a condensate receiver, and a gravity separator. Steam, injected through a perforated pipe in the still, provides the heat for vaporization of the waste. Vapor is condensed and collected as a liquid in the condensate receiver. Liquids with similar boiling points and different densities may be separated by gravity separation in the condensate receiver (EPA, 1987).

In continuous steam stripping, waste flows down the column while steam flows up as in air stripping. The column is designed to promote transfer of contaminants to the gas phase by causing effective heat transfer to the waste, by creating turbulence in the waste, and by providing a large waste surface area. Different liquid-vapor equilibria exist at various heights in the column, with the highest relative concentration of the most volatile component being on the top (Blaney, 1986); however, all volatiles are swept out together in steam stripping.

Applications

Steam stripping is able to strip compounds with lower volatility than those removed by air stripping. The technology is reported to be effective for removal of high concentrations of organics, ranging from 1 to 20 percent (EPA, 1986a). Volatile organics, as well as semi-volatiles such as phenols, ketones, and phthalates, are good candidates for removal by steam stripping. Steam stripping is currently used at some commercial and industrial facilities to treat RCRA-spent solvent wastewaters (Turner, 1989). Hydrogen sulfide and ammonia can

also be removed by this process (EPA, 1987). Steam stripping is reported to be capable of removing over 99 percent of ammonia in high strength industrial wastes (Wickramanayake et al., 1989).

Advantages and Disadvantages

Steam stripping is a well demonstrated technology and commonly used in industry. As compared to air stripping, it may be used to treat less volatile compounds. However, the process generates a concentrate that requires treatment or disposal if recycling of the concentrate is not an option. This process is also expensive to operate, and is cost effective only when a source of waste heat or low cost fuel for producing steam is available.

TECHNOLOGY DATA SHEET

DISTILLATION

Description

Distillation is a unit operation that involves separating components according to their boiling point characteristics. The contaminated solution is heated for separation into a vapor phase and a liquid phase. The more volatile components will escape as vapor and can be separated according to their boiling point temperatures. The less volatile compounds are left in the concentrate. A fraction of condensate can be returned to the distillation unit so that the condensate is in contact with the rising vapors, with the result that the vapors are enriched volatiles and depleted in "heavier" organics (EPA, 1986a). The process can be used to separate various volatile compounds or to separate mixtures of various organics into light and heavy fractions. The light fractions can usually be provided in higher purity for recycle or used as a boiler feed, while the heavy fractions are likely to require further treatment. Distillation processes can be operated continuously or batchwise.

Applicability

The primary use of distillation is for reclaiming spent solvents from industrial processes or purifying certain aqueous wastes. Typical candidates for treatment by distillation are acetone, alcohols, chlorinated organics, hydrocarbons, and ketones (EPA, 1986a; Blaney, 1986).

Advantages and Disadvantages

Distillation is a well developed process that is easy to operate and that allows organic solvents to be recycled as distillates which are removed as "light ends." "Heavy ends" or "still bottoms" generally require further treatment or disposal. Distillation is not a feasible alternative for dilute solutions, such as contaminated groundwater, where the organics concentrations are too low to justify the heating requirement.

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TECHNOLOGY DATA SHEET

BIOLOGICAL REACTOR

Description

Biological reactors use microorganisms to remove organic contaminants from water. The microorganisms use the organics as a substrate for growth. Additional nutrients, nitrogen and phosphorus, are required for microbial activity. Two basic categories of bioreactors exist, anaerobic and aerobic. The difference between the two is that aerobic systems require an oxygen source, while anaerobic degradation is accomplished in an oxygen-free environment. Aerobic reactors are the more common and more easily operated biological systems. Several different types of such reactors exist, such as activated sludge systems, trickling filters, rotating biological contactors, and immobilized cell reactors.

Applications

Most organic compounds can be biologically degraded by the appropriate microorganisms. Some compounds, such as large, complex chlorinated organics and some volatile chlorinated organics, are more easily degraded anaerobically than aerobically. High concentrations of organics or the presence of metals may be toxic to the organisms, and pretreatment may be required. Nitrate removal can be accomplished by biological denitrification, a process commonly implemented in wastewater treatment systems.

Advantages and Disadvantages

The major advantage of biodegradation is that it is a natural process that will generally reduce the toxicity of the contaminant. Disadvantages of biological reactors include: generation of large amounts of sludge (especially in aerobic processes), possible formation of toxic by-products, and relatively low removal efficiencies that make additional treatment necessary. Emissions of volatile organics may also be a problem. It is also generally

difficult to treat very low levels of organics. High or varying concentrations of organics or metals may have a toxic effect on the microorganisms.

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TECHNOLOGY DATA SHEET

IN SITU BIOLOGICAL TREATMENT

Description

In situ aerobic biological treatment of groundwater involves the stimulation of biological growth in the contaminated zone in order to reduce the contaminant concentrations. Microorganisms that can use some or all of the contaminants as substrate will normally exist in a contaminated environment. The microorganisms are stimulated to increase their biological growth and consumption of contaminants through addition of an oxygen source and essential nutrients and micronutrients. Anaerobic processes also exist.

The aerobic *in situ* treatment system generally consists of injection wells for injecting an oxygen source and required nutrients and extraction wells for monitoring and recovering by-products. The most common oxygen source is dilute hydrogen peroxide. Inocula of acclimatized bacteria may be added as needed. The treatment efficiency is measured in terms of contaminant reduction, dissolved oxygen, and bacterial growth.

In situ treatment may also be carried out as an anaerobic process. This requires that anaerobic conditions are established in the contaminated zone. The operation of such a system is essentially the same as for the aerobic, except that no oxygen addition is involved. The anaerobic and aerobic *in situ* processes may also be combined and operated in series.

Applications

In situ biodegradation has been used for various applications such as gasoline spills and wood-treating wastes containing semivolatile and nonvolatile organics (EPA, 1986c, Litchfield, 1986). While it was previously thought that trichloroethylene (TCE) was only anaerobically degradable, recent *in situ* studies have demonstrated that TCE can also be treated aerobically *in situ* (Roberts et al., 1989).

Even though most compounds can be biologically degraded, it should be noted that *in situ* treatment is dependent on other process-controlling factors such as geological and hydrological conditions.

Advantages and Disadvantages

The major advantages of *in situ* biological treatment are:

- Can be carried out in place
- No sidestreams generated
- Only environmentally safe compounds are added
- Relatively inexpensive operation.

Disadvantages include:

- Level of cleanup generally less than for aboveground treatment trains
- May be difficult to control
- Difficult to treat broad mixtures of compounds.

TECHNOLOGY DATA SHEET

VACUUM EXTRACTION

Description

Vacuum extraction is an *in situ* treatment technology that involves air stripping of contaminants by inducing a vapor flow through the soil thereby displacing contaminated soil gas with uncontaminated gas. As air is pulled through the soil medium, organics which are in free phase, in solution, and sorbed onto the soil are volatilized into the air.

Vacuum extraction can be accomplished by installing perforated pipes, vertically or horizontally (depending on the depth to the water table), and exerting a vacuum through the soil using a pump. Implementation requires that certain geological as well as chemical characteristics are satisfied (Hutzler et al., 1990). Sandy soils and gravels are preferred, but vapor extraction may be used for silts and clays depending on degree of saturation. Since this technology involves transfer of the contaminants to the vapor phase, emission control must be included as part of the system.

Applications

Vacuum extraction is primarily applicable for removal of volatile organic compounds (VOCs) from soils above the water table (EPA, 1988a; Hutzler et al., 1990). Efficient removal by this technology requires contaminants of relatively high volatility. Contaminants with Henry's constants greater than $1 \times 10^{-3} \text{ atm}^3/\text{mole}$ and vapor pressures greater than 1.0 mmHg indicate that vapor extraction may be suitable. Certain geological requirements, such as those specified above, must also be satisfied for vacuum extraction to be applicable.

Advantages and Disadvantages

The major advantage of vacuum extraction is that it is carried out *in situ* so that the soil and underground structures can be left in place. The movement of air through the contaminated

soil also promotes biodegradation of the contaminants. Additionally, the system is fairly easy to operate. The major disadvantage of this technology is that the contaminants are not destroyed, but transferred from soil to air, and additional aboveground treatment is, therefore, required.

TECHNOLOGY DATA SHEET

SOIL WASHING

Description

Soil washing is based on the principle of contaminant removal from soil by washing with a solution. Washing agents can include water, acids, surfactants, solvents, or chelating agents. Contaminated soil is excavated and placed in a reactor for mixing with the extracting solution. Sorbed contaminants are transferred to the liquid phase by dissolving, by forming an emulsion, or by a chemical reaction with the solution. When extraction is complete, the soil particles are physically separated from the solution, and the treated soil can be returned to the excavation. The extractant containing the contaminants requires further treatment for recycling or disposal.

Applications

By selecting the appropriate washing solution, soil washing technology can potentially be used to treat inorganics, metals, organics, or radionuclides in soil. Application of a soil washing reactor system at four sites in the Netherlands demonstrated greater than 80 percent removal efficiencies for polynuclear aromatic hydrocarbons (PNAs), cyanides, heavy metals, mineral oil, and halogenated hydrocarbons (Assink, 1985). Soil structure and chemistry are important variables in applying the technology successfully and require evaluation on a site-by-site basis.

Inorganics that can be washed from soil with water include soluble salts such as carbonates of nickel, zinc, and copper. Dilute solutions of sulfuric, hydrochloric, nitric, phosphoric, and carbonic acid have been widely used in industry to extract metal ions by dissolving basic metal salts including hydroxides, oxides, and carbonates. Heavy metals can be removed from soils by complexing and chelating agents such as citric acid, ethylenediaminetetraacetic acid (EDTA), and diethylenetriaminepentaacetic acid (DTPA) (EPA, 1985, 1987). Arsenic

and selenium removal can be enhanced with the addition of oxidizers such as hydrogen peroxide (EPA, 1986a).

Organics that can be removed from soil by water washing include low to medium molecular weight aldehydes, ketones, and aromatics and lower molecular weight hydrocarbons such as trichloroethylene and tetrachloroethylene. Other basic organic groups like amines, ethers, and anilines can be flushed from soil by washing with an acidic solution. Surfactants have been employed to enhance the recovery of petroleum products and PCBs (EPA, 1985). Removal of organochlorine compounds by extraction with a solvent mixture of toluene, kerosene, and octanol was demonstrated in laboratory experiments on sludges from Rocky Mountain Arsenal (A.D. Little, 1988).

The use of water, inorganic salts, mineral acids, and complexing reagents to extract radionuclides from soils and tailings was reviewed by the EPA (EPA, 1988b). These extraction techniques have been applied as bench-scale or pilot-plant testing for removal of radium and thorium but have not been implemented for remediation of a radiologically contaminated site. Water was shown to be ineffective, removing only 10 percent of the radium and virtually none of the thorium from soils tested. Inorganic salt solutions, mineral acids, and complexing reagents all showed high removal percentages in some applications (EPA, 1988b).

Advantages and Disadvantages

The primary advantage of soil washing is that a variety of types of contaminants can potentially be removed from soils in a reactor under relatively controlled conditions. The process is flexible and can be designed for specific mixtures of contaminants, although treatment of mixtures may require multiple stages using different washing solutions.

Contaminants are not destroyed but are transferred to the aqueous phase. The technology requires a subsequent separation process for liquids and solids and treatment of the resulting solution for recycling or disposal. Soil washing may require the addition of potentially hazardous substances as washing agents. Residual soil washing chemicals remaining in the soil may also be a problem.

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TECHNOLOGY DATA SHEET

CHEMICAL PRECIPITATION

Description

Chemical precipitation is the process of making dissolved chemical constituents insoluble so that they can be separated from the liquid (EPA, 1985; Wentz, 1989). Precipitation is usually accomplished by adding a chemical that forms an insoluble compound with the target contaminant. Hydroxide and sulfide precipitation are commonly used for removing heavy metals. Typical precipitating agents include sodium hydroxide, lime, ferric hydroxide, and sodium sulfide. The precipitates are often flocculated into larger particles (flocs) with the help of coagulants prior to solids removal.

Applications

The K-1232 Liquid Chemical Treatment Facility at Oak Ridge uses chemical precipitation for removal of heavy metals from plating operation aqueous wastes. The treated waste waters are released under NPDES standards (Sferrazza, 1990).

An iron coprecipitation process has been used at Oak Ridge for removing uranium from nitrate-containing wastes and in the Uranium Mill Tailing Remedial Action (UMTRA) program for removing uranium, radium, and other contaminants from surface runoff wastes generated during remedial action. During pilot-scale testing of this process at Hanford, reduction of uranium in groundwater from 3,460 ppb to 1 to 7 ppb was demonstrated (Hodgson, 1989).

Advantages and Disadvantages

Chemical precipitation systems are relatively simple to operate and equipment and chemicals are readily available. However, the method generates a sludge that requires further treatment or disposal. If present, organometallic complexes may inhibit precipitation of the

metals. There is no upper concentration limit for treatment but the lower concentrations are limited by equilibrium solubilities of the individual precipitates. The removal efficiencies are determined by the solubility products of the salts formed. However, some contaminants may be coprecipitated with the sludge that is formed, and may be removed to concentrations below their solubility limits. Treatability testing is generally required.

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TECHNOLOGY DATA SHEET

OXIDATION/REDUCTION OF INORGANICS, RADIONUCLIDES, AND METALS

Description

The chemical reduction-oxidation (redox) process involves a change of the oxidation state of the reactants; one is increased while that of the other reactant is reduced. Common oxidizing agents include ozone, hypochlorite, and chlorine. Common reducing agents include sodium borohydride, sulfur dioxide, and ferrous sulfamate (EPA, 1985, 1986a).

The purpose of redox treatment of inorganic compounds (excluding heavy metals) in water is generally to break a compound into simpler, less toxic constituents. Examples are the conversion of sodium cyanide to carbon dioxide and nitrogen using alkaline chlorination and the conversion of ammonium to nitrogen and water using sodium nitrite (Marin et al., 1979).

The use of redox treatment of waste streams containing metals is typically required to enhance a subsequent precipitation step. The redox reaction is used to adjust the metal to an oxidation state that will result in the formation of an insoluble metal salt precipitate that can then be physically removed from the bulk of the aqueous waste stream.

An example is the use of sulfur dioxide to reduce hexavalent chromium to trivalent chromium, which is then precipitated as chromous hydroxide. In general, the use of redox in conjunction with precipitation for the removal of heavy metals is a well established water treatment method.

Applications

A typical redox process for removal of cyanide involves conversion of cyanides to cyanates with a 15 percent solution of sodium hypochlorite at a pH > 10. The cyanates are then further oxidized to N₂ and CO₂ with the sodium hypochlorite solution at pH 8.5. Complete oxidation takes approximately 10 minutes (Marin et al., 1979; EPA, 1980). This type of process is common for treatment of electroplating rinse water.

Reduction of hexavalent chromium to its trivalent state followed by precipitation is a standard process step for treating chromium-bearing aqueous wastes. The solution pH is first adjusted to a pH of 2 to 3 by addition of hydrochloric or sulfuric acid. A reducing agent, typically sulfur dioxide or sodium metabisulfite, is then added. After the reaction is completed, the pH is adjusted to 7.5 to 8.5 using lime or caustic. At this pH, chromium hydroxide has its minimum solubility and precipitates (Lanouette, 1977).

The use of redox reactions for the removal of trace quantities of uranium and transuranic elements from groundwater has not been demonstrated. Processes for recovery and purification of uranium and transuranic elements, however, rely heavily on adjustment of oxidation states. These processes include precipitation as well as acid and solvent extraction. The separation of plutonium from cerium by extraction with tributyl phosphate (TBP) requires that the plutonium be oxidized to the tetravalent state without oxidation of cerium to its tetravalent state. Similarly, the separation of plutonium from uranium requires that the plutonium be trivalent and uranium hexavalent (Benedict et al., 1981). Process solutions typically contain transuranic elements in concentrations orders of magnitude above those required to meet discharge limits.

The oxidation states and solubilities of uranium and transuranic elements at trace concentrations in groundwater have been studied by several researchers in recent years (Nitsche et al., 1988; Kim et al., 1988; Nash et al., 1988; Cleveland et al., 1985). In

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general, they found Pu(V) and Pu(VI) to be the oxidation states of the soluble plutonium species. Presumably, plutonium solubility could be reduced by reduction to Pu(III) or Pu(IV). The solubility is enhanced by the presence of carbonate and fluoride, which form complexes with the plutonium. Americium solubility is controlled mainly by the formation of radiocolloids.

Advantages and Disadvantages

The use of redox processes has the advantage that often inorganic contaminants may be transformed into less hazardous forms. The ability to adjust oxidation states of metals is advantageous and in some cases necessary for a subsequent treatment process, such as precipitation. A disadvantage of the use of chemical redox reactions is undesirable side reactions. These include the reduction or oxidation of organics and the production of chlorinated organics if the selected process is chlorination (Rice and Gomez-Taylor, 1985). The process will also produce a sludge that requires further treatment or disposal.

TECHNOLOGY DATA SHEET

CHEMICAL OXIDATION OF ORGANICS

Description

Chemical oxidation is used to degrade hazardous organic materials to less toxic compounds. A number of different chemical oxidation processes exist for treatment of organic contaminants. These include chlorination, ozonation, and treatment by a combination of UV radiation, and ozone, and/or hydrogen peroxide (EPA, 1985, 1986a; Wentz, 1989).

Chlorination: In this process chlorine is added to water to oxidize both organics and inorganics. Chlorine, which is added in its elemental form (gas), chlorine dioxide gas, or hypochlorite salt, is a strong oxidizing agent in aqueous solutions. The primary use of chlorination has been for disinfection of drinking water. In addition to oxidizing the inorganic and organic molecules in water, chlorine also reacts with the organics and thereby forms potentially toxic chlorinated by-products.

Ozonation: Ozone is a strong chemical oxidant that has been used for purification, disinfection, and odor control of drinking water. Ozone is generated from air or oxygen and is applied by bubbling the gas through the water being treated. Ozone efficiently breaks down some easily oxidizable organics, but has generally been shown to be an ineffective oxidant for halogenated organics at reaction times and concentrations normally used in drinking water treatment. Complete oxidation of organic species to carbon dioxide and water may require high ozone dosage and long contact times. If inorganics, such as iron, are present, their oxidation may inhibit the destruction of organics.

UV/Ozone/Hydrogen Peroxide: The use of ultraviolet (UV) radiation in combination with ozonation has been found to catalyze the oxidation process and is now in common use. This form of treatment is accomplished by contacting the ozone and the contaminated water in a

closed reactor in the presence of UV light. The combination of UV and ozone treatment makes it possible to oxidize compounds that would not be oxidized by ozone treatment only. UV radiation causes destruction or weakening of the chemical bonds in the organic compounds, thereby acting as a catalyst for the oxidation process. Hydrogen peroxide can be used in combination with UV light as an alternative to ozone, or all three may be combined.

Complete oxidation of organics results in the formation of carbon dioxide and water. In waste treatment, complete oxidation of all the contaminants is difficult and expensive to achieve, so a variety of low molecular weight organics are formed in the process. Since various degrees of oxidation occur in complex mixtures, it is important that the system be designed for removal of selected target contaminants. A thorough characterization of by-products is necessary.

Applications

Chemical oxidation processes have been reported for dilute waste streams containing aldehyde, mercaptans, phenols, benzidine, unsaturated acids, and some pesticides (Kiang and Metry, 1982).

The UV/Ozone/Peroxide system as marketed by ULTROX International has been used for pilot-scale and full-scale treatment of a variety of organic contaminants (Fletcher, 1987; Barich, 1990). In a pilot-scale test, the system was found to reduce trichloroethylene (TCE) from 200 ug/L to 2.6 ug/L and carbon tetrachloride from 10 ug/L to 2.9 ug/L. The ULTROX system has been used full-scale for treating 200,000 gallons of tetrahydrofuran-contaminated groundwater. The contaminant concentrations were reduced from 5,000 ug/L to nondetectable levels. Groundwater contaminated with TCE, tetrachloroethylene (PCE), and 1,1,1-trichloroethane at 470, 96, and 166 ug/L, respectively, was treated to below drinking water standards in pilot studies. Pilot studies were also conducted and demonstrated

the reduction of polychlorinated biphenyl (PCB) concentrations from 50 ug/L to less than 1 ug/L.

Similar systems are manufactured by Solarchem (Ontario, Canada) and Peroxidation Systems, Inc. (Gardenia, California).

Advantages and Disadvantages

Chemical oxidation of organic contaminants has the advantage that the contaminants are destroyed in the process. On a cost basis, UV/ozone/peroxide treatment is competitive with GAC treatment. Natural organics and inorganics may interfere with the oxidation process and increase the oxidant requirements. Undesirable organic by-products may also be formed.

TECHNOLOGY DATA SHEET

SORPTION OF INORGANICS, RADIONUCLIDES, AND METALS

Description

Sorption is a term commonly used to refer to both adsorption and absorption. Adsorption is the physical adhesion of molecules or particles to the surface of a solid adsorbent without chemical reaction. Absorption involves the transfer of the molecules or particles from one phase to the other so that they actually become a part of the other phase (medium). Absorption may be physical or chemical in nature.

A number of different sorption processes exist for treatment of inorganics, metals, and radionuclide contaminants in water. These include ion exchange, activated alumina, a ferrite process, and other processes (EPA, 1985, 1986a; Schweitzer, 1979).

Ion Exchange: The ion exchange process is a reversible exchange of ions between liquid and solid phases. Ions held by electrostatic forces to charged functional groups on the surface of an insoluble solid are replaced by ions of similar charge in a solution. Ion exchange is stoichiometric, reversible, and selective in removal of dissolved ionic species. The technology has been used successfully to remediate wastewater and groundwater containing heavy metals and uranium. It is a standard processing technique for purification of uranium and transuranic elements. The ion exchange system typically consists of a column packed with an ion exchange material. This material is commonly a synthetic acidic or basic resin in bead form, although in some cases, manufactured and naturally occurring aluminum silicate clays or zeolites are used.

Activated Alumina: Activated alumina is a porous form of aluminum oxide with a large surface area. It will adsorb liquids, vapors, and gases. For removal of aqueous contaminants, activated alumina is typically used in a column similar to that for ion

exchange. It has proven to be successful in the removal of arsenic and fluoride from groundwater (Rubel, 1980; Frankel and Juergens, 1980). Adsorbed species can be removed by flushing the column with a suitable chemical solution, generating a concentrated side stream.

Ferrite Process: This process involves the introduction of ferrite particles into a waste stream. Inorganic contaminants present in the waste stream will sorb to the particles which are then removed by physical separation. The ferrite process also has the capability of being used in a column similar to ion exchange.

Applications

Ion exchange was used at Hanford (Weiss, 1990) for removing uranium from 8,000,000 gallons of groundwater. The uranium had leached from a soil column that had been used for disposal of low-level process waste. The ion exchange process recovered 94 percent of the uranium.

The Savannah River Site's Effluent Treatment Facility uses ion exchange to remove cesium and mercury from low-level wastewater in conjunction with reverse osmosis and evaporation. The treated water is discharged to an NPDES-regulated outfall (Sferrazza, 1990).

Activated alumina is used to remove small amounts of fluoride and arsenic from potable water and wastewater (Rubel, 1980; Frankel and Juergens, 1980). The fluoride adsorption process is pH dependent with optimal removal occurring at pH 5. Research indicates that selenium can also be removed using activated alumina (Yuan et al., 1983).

Advantages and Disadvantages

Sorption of inorganics, metals, and radionuclides is a standard technique for removal and concentration of these contaminants. The major disadvantage to sorption processes is that

they produce a concentrated liquid side stream resulting from regeneration. If not regenerated, the sorbent must be disposed as a solid waste.

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TECHNOLOGY DATA SHEET

GRANULAR ACTIVATED CARBON ADSORPTION OF ORGANICS

Description

Granular Activated Carbon (GAC) adsorption is based on the attraction of organic molecules in solution to the surface of the activated carbon. The adsorption process is dependent on the strength of the molecular attraction between the carbon and the organic contaminant, the type and characteristics of the carbon, and the pH and temperature of the solution. Nonpolar organic compounds of low water solubility are most easily adsorbed (EPA, 1986a).

GAC adsorption is one of the most frequently used techniques for treating aqueous streams contaminated with organics. The carbon is placed in columns that are operated until the effluent concentration reaches unacceptable levels. At this point the carbon has become saturated with the contaminants and must be regenerated for reuse. The carbon is generally regenerated thermally. Pretreatment is typically required for removal of oil, grease, and suspended solids.

Applications

GAC adsorption is an effective process for removing a variety of organics from water. It has been successful for carbon tetrachloride, chloroform, DDT, benzene, acetone, methylene chloride, phenol, trichloroethylene, and xylene among others (EPA, 1985). In general, GAC can reduce these contaminants from mg/L concentrations to low ug/L concentrations.

The Rocky Mountain Arsenal has used GAC adsorption extensively for treatment of groundwater (PMSO, 1987a, 1987b). Contaminants removed include trichloroethylene, dibromochloropropane, diisopropylmethyl phosphonate, dicyclopentadiene, and various pesticides such as dieldrin and aldrin.

Advantages and Disadvantages

GAC adsorption is a well known and developed technique for removing organic contaminants from water. The adsorbability varies between different classes of organics, but most of them can be removed by this method. The major disadvantage of GAC adsorption is that it requires energy-intensive regeneration or disposal of the carbon, and large amounts of carbon are required for poorly adsorbable compounds, such as chlorinated volatile organics. Residuals include spent carbon and/or waste streams from the regeneration process.

TECHNOLOGY DATA SHEET

SOLIDIFICATION/STABILIZATION

Description

Solidification is a process that mechanically binds contaminants to the solidification agents to reduce the contaminant mobility. The process produces a solid matrix of waste with high structural integrity. Stabilization usually involves the addition of a chemical reagent to react with the contaminant producing a less mobile or less toxic compound. Solidification and stabilization are usually used together to immobilize a waste. Two major forms of solidification/stabilization, pozzolanic-based and cement-based, have been used extensively to treat hazardous waste (EPA, 1985, 1986e).

Pozzolanic-Based: This solidification method uses materials that form a solid mass when mixed with hydrated lime. Pozzolanic materials include diatomaceous earth, blast-furnace slag, ground brick, and some fly ashes. After mixing of the waste and pozzolan, hydrated lime is blended into the mixture. The resulting moist mixture is packed into a mold and allowed to cure.

Cement-Based: Cements are often used as binding agents, along with pozzolanic materials, to improve the strength and chemical resistance of solidified waste. The types of cement used for solidification can be selected to emphasize a particular cementing reaction.

Applications

Solidification/stabilization is being used for low-level radioactive and RCRA mixed wastes at the Hanford nuclear reservation (Sferrazza, 1990). After mixing the wastes with portland cement, fly ash, and clay, the cemented wastes are poured into specially constructed near-surface concrete vaults that isolate the cement product from the environment (Collins, 1988).

The combination of waste solidification and placement in concrete vaults is designed to contain the waste materials for at least 10,000 years (DOE, 1990).

Record of Decision (ROD) documents for at least seven Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites have identified solidification/stabilization as the remedial technology of choice for immobilization of heavy metal contaminants. These sites include the Selma Pressure Treating Company, CA; Flowood, MS; York Oil, NY; Chemtronics, NC; Bailey Waste Disposal, TX; Mid-State Disposal Landfill, WI; and Love Canal, NY.

Various solidification/stabilization techniques have been used at DOE sites throughout the United States. The 513 Solidification Unit at Lawrence Livermore National Laboratory uses cement, Envirostone™, Petroset™, and Aquaset™ to solidify liquid wastes. The Los Alamos National Laboratory uses an in-drum solidification technique for immobilization of TRU solid and liquid wastes. Plutonium precipitation sludge is immobilized in-drum at Mound using portland cement. The Oak Ridge Facility uses a fly ash cement to immobilize a treatment pond sludge containing uranium, chromium, nickel, cadmium, and technetium. Portland cement is used to immobilize waste sludge in Rocky Flats pondcrete and saltcrete processes (Sferrazza, 1990).

Advantages and Disadvantages

Solidification/stabilization is a well established process for reducing the mobility and toxicity of hazardous wastes. Solid wastes containing radioactive contaminants are well suited for this process as it contains and reduces the mobility of the radioactive materials. Solidification/stabilization processes increase the volume of the treated wastes. Organic compounds, if present, often interfere with the desired solidification and stabilization process.

TECHNOLOGY DATA SHEET

PHYSICAL SEPARATION

Description

Soil contaminants are often found to be associated with particular size fractions of soils, most often the fine particle sizes. Fractionation of the soil based on particle size can, therefore, be an effective means of reducing the volume of the material that requires treatment. The processes effective for performing soil size fractionation include screening, classification, flotation, and gravity concentration (EPA, 1988c).

Screening: This process is the mechanical separation of materials based on their size. This separation is usually obtained using a uniformly perforated surface. The material is passed over the screen. The larger particles are retained on the surface and the smaller particles pass through. Screening is usually limited to particles larger than 250 μm in diameter (Perry and Chilton, 1973).

Classification: This process is used to separate particles based on their settling rate in a fluid, such as water. A single stage classifier will typically make a single separation, with faster settling materials going out the underflow and the slower going out the overflow. There are three types of classifiers: nonmechanical, mechanical, and hydraulic (Perry and Chilton, 1973).

Flotation: The injection of air into a liquid suspension can cause low-density solids and hydrocarbon solids to float to the surface for removal. This method is used extensively in the mining industry for concentration of minerals. Microbubbles formed by injection of air attach to particles, become trapped under larger particles, or become part of flocs. These particles with the attached air bubbles have a combined specific gravity less than that of water and float to the surface (Ives, 1984).

Gravity Concentration: This technique uses density differences of materials to effect separation. Gravity concentration can be implemented using sluices, shaking tables, and the traditional miner's pan. All of these devices keep the particles slightly apart so that they can move relative to each other and separate into layers of light and dense materials (Burt, 1984).

Applications

Flotation and other physical separation techniques are used to recover copper, uranium, zirconium, and magnetite by the Palabora Mining Company in South Africa (Burt, 1984). The method has also been used for removal of radium from uranium mill tailings in Elliot Lake (Raicevic, 1970). During laboratory testing, flotation was found to reduce radium concentrations from 290 pCi/g to 57 pCi/g.

Several soil decontamination processes in the Netherlands use gravity concentration and flotation for removal of fine particles and organics from extracting agents (Assink, 1985; EPA, 1988c). Systems similar to this are in the pilot-stage in the United States (Hazardous Waste Consultant, 1989). Pilot plant testing at Rocky Flats in the early 1970s (Garnett et al., 1980) showed that soils contaminated with 45, 284, and 7,515 pCi/g plutonium were reduced to 0.5, 12, and 86 pCi/g, respectively, using physical separation. The cleaned soil fraction ranged from 58 percent to 87 percent of the original volume.

Advantages and Disadvantages

Screening is an inexpensive method for separating particles, but screens are subject to plugging, which can greatly decrease their efficiencies. The use of dry screening generates dust emissions that must be controlled.

Classifiers have high continuous processing capabilities and are very reliable, but soils containing clay or sandy soils containing humus materials can be difficult to process.

Flotation can achieve very high separation rates if the materials are suited to such treatment, but it is a complex and expensive process.

Gravity concentration is a highly efficient and well proven technique, but it has a relatively low process capacity.

Wet processes may produce a liquid waste stream requiring treatment or disposal.

TECHNOLOGY DATA SHEET

ELECTRODIALYSIS OF INORGANICS AND METALS IN WATER

Description

Electrodialysis is a membrane separation process that can be used to remove ionic species from a water stream. A typical electrodialysis cell consists of an anode and a cathode separated by an anion permeable membrane near the anode and a cation permeable membrane adjacent to the cathode. An electrical current is applied across the cell. As the water flows through the channel between the two membranes, the positively charged ions are drawn through the cation permeable membrane to the cathode. Likewise, the negatively charged ions are drawn to the anode. As a result there is a significant reduction in ionic species concentration in the intermediate channel containing the treated effluent (Weber, 1972). An electrodialysis system generally consists of many thin cells stacked in parallel. The resultant waste side stream of anion and cation concentrated water requires further treatment or disposal. Periodic cleaning of the system can be performed by reversing the electrolytic potential across the cells.

Applications

Electrodialysis can be applied as a treatment method to contaminants including metals and inorganics that are charged species in water. Electrodialysis has been extensively used on a commercial scale for desalination of water (Buros, 1989). Treatment of metal-bearing hazardous waste streams, such as plating wastes, is another typical application for electrodialysis (Grosse, 1986).

Advantages and Disadvantages

Electrodialysis is an effective method for concentrating some charged species from a waste stream into a reduced volume of wastewater. Compared to reverse osmosis, the membranes

used in electrodialysis are more tolerant of the chemical environments of waste streams and are easier to clean (Buros, 1989; Grosse, 1986).

Contaminants are not destroyed by electrodialysis, but are concentrated into a lower volume waste stream that requires treatment and disposal. Pretreatment of some influent streams may be required to prevent membrane fouling.

TECHNOLOGY DATA SHEET

REVERSE OSMOSIS

Description

Reverse osmosis (RO) removes contaminants from aqueous wastes by passing the waste stream, at high pressure, through a semipermeable membrane. At typical operating pressures of 200 to 800 psi, clean water or permeate is forced through the membrane leaving a concentrated waste stream behind as membrane rejection. High pressure acts as the driving force to overcome the osmotic pressure created by higher concentrations of solutes in the rejection stream. The process produces a concentrated waste stream of reduced volume that requires further treatment or disposal.

Applications

Membranes in RO units are typically impermeable to fine particles and many dissolved species. In general, good removal can be expected for high molecular weight organics and charged anions and cations. Multivalent ions are treated more effectively than univalent ions (EPA, 1985).

The RO process has been developed and extensively applied for desalination of brackish waters (Dykes and Conlon, 1989) and in treating metal wastes from plating baths (EPA, 1986a). In addition to these more common applications for inorganics and metals, the technology has been applied for treating waste streams of organics and radionuclides.

Removal of organic contaminants from dilute waste streams were reported by EPA (1985). Pilot-scale testing of an RO unit demonstrated 90 to 98 percent removal from the permeate for 1,2-dichloroethane, chloroform, diethyl ether, and tetrahydrofuran. Trichloroethene, benzene, bromoform, hexane, 1,1,1-trichloroethane, and 1,1-dichloroethane showed 99 percent or greater removal from permeate. PCBs and pesticides were also successfully

removed from groundwater in test applications of a mobile RO unit at waste sites in Canada (EPA, 1986a).

RO was used by Hodgson and Garrett (1989) to treat groundwater containing a mixture of radioactive materials, including uranium and technetium, and nitrate. All contaminants in the effluent stream were reduced to concentrations below MCLs.

Advantages and Disadvantages

The primary advantage of RO is that this process can be used to successfully treat different types and combinations of contaminants in water to relatively low concentration levels.

Disadvantages are that contaminants are not destroyed by this process but are concentrated to a smaller liquid volume that still requires treatment or disposal. Pretreatment of the influent stream to prevent fouling, plugging, and chemical attack on the membrane is required.

This process also requires the use of cleaning solutions that will require treatment or disposal.

TECHNOLOGY DATA SHEET

IN SITU BIOLOGICAL TREATMENT

Description

In situ biological treatment of soils involves stimulating existing or introduced soil microorganisms that will use organic contaminants in the soil as a substrate for growth. Both aerobic and anaerobic degradation of contaminants is possible *in situ* depending on the availability of oxygen. In both cases, stimulation of biological growth and consumption of contaminants is typically achieved by the addition of essential nutrients such as ammonia and phosphate. Depending on the depth of soils to be treated, nutrient solutions can be added by sprinkling and subsequent infiltration or by a system of injection wells. Stimulation of aerobic degradation also requires the addition of an oxygen source such as hydrogen peroxide for the soil microorganisms. Extraction wells are typically installed for monitoring and recovery of by-products (EPA, 1985, 1986c).

Applications

In situ biological treatment is particularly useful where soil excavation is difficult or extremely expensive. The method has usually been applied as part of a combined *in situ* treatment of organics in soils and groundwater at a site. Soil and groundwater contamination from spills of gasoline and other petroleum products has been successfully treated by *in situ* bioreclamation to where aquifer contamination from the site was below drinking water standards or was nondetectable (EPA, 1985). An *in situ* biological treatment system at Kelly Air Force Base demonstrated significant degradation of aliphatic hydrocarbons and chlorinated aromatics in soils and groundwater (Wetzel et al., 1986). These applications used aerobic degradation; anaerobic biodegradation for *in situ* applications is more difficult because of problems in maintaining an oxygen-free environment and because of temperature sensitivity of the microbes. Even though most organic compounds can be biologically

degraded, it is important to note that the applicability of *in situ* biological treatment is very dependent on geologic and hydrologic conditions at the site.

Advantages and Disadvantages

In situ biological treatment of soils can be carried out in place and is, therefore, relatively inexpensive. Only environmentally safe compounds are added in the treatment, and no side streams are generated. The *in situ* process may be difficult to control and the level of cleanup is generally lower than for more controlled aboveground treatment trains. Treatment of a broad mixture of contaminants can also be problematical.

TECHNOLOGY DATA SHEET

BIOLOGICAL REACTORS/TEST CELLS FOR TREATMENT OF ORGANICS IN SOILS

Description

Soil contaminated with organics can be treated by microbial degradation in a biological reactor or test cell by mixing the soil with water to create an aqueous slurry. The slurry is mechanically agitated in the reactor to keep the solids suspended and to maintain the appropriate environmental conditions for microorganisms to use and biodegrade the organic compounds present. The slurry is dewatered when biodegradation is complete. The residual water may require further treatment prior to disposal.

There are two basic classes of bioreactors: aerobic and anaerobic. Aerobic systems require an oxygen supply for the microorganisms, while anaerobic organisms require an oxygen-free reactor environment. In both types, optimum conditions for microbial growth may require the addition of nitrogen and phosphorous as nutrients and acids or bases for pH adjustment. Aerobic reactors are more commonly used and are easier to operate than anaerobic reactor systems.

Applications

Organic compounds, in general, can be degraded by the appropriate microorganisms. Aerobic degradation is faster and more complete for petroleum hydrocarbons, aromatics, halogenated aromatics, polyaromatic hydrocarbons, phenols, halophenols, biphenyls, organophosphates, and most pesticides and herbicides. Halogenated, low molecular weight hydrocarbons and large, complex chlorinated organics are more easily degraded by anaerobic organisms (EPA, 1985). The presence of metals or high concentrations of organics in soils may be toxic to microorganisms and would require pretreatment before introduction into a bioreactor system.

Advantages and Disadvantages

Biodegradation is a natural process that will generally reduce the amount and toxicity of contaminants. Relatively low removal efficiencies and formation of toxic by-products are potential problems associated with biological treatment. Wastewater generated from dewatering of the resulting soil slurry may require additional treatment. The process may also produce emissions of volatile organic compounds.

TECHNOLOGY DATA SHEET

INCINERATION

Description

Incineration is a well developed, proven technology for thermal oxidation treatment of organic compounds. This technology has been applied to solids, liquids, and gases, and is appropriate for the treatment of soils contaminated with organic compounds.

Incineration is the controlled combustion (oxidation) of organic compounds under net oxidizing conditions (i.e., the final oxygen concentration is greater than zero). Temperatures in the incinerator are generally in the 1,200 to 2,300°F range (EPA, 1986a), which results in the destruction of organic compounds. Removal efficiencies for organics are generally greater than 99.99 percent (EPA, 1986a), while inorganic components, such as soil and metals, pass through the system. Fuel must be added to the process if insufficient organics are present to sustain combustion, resulting in a large amount of energy being used to heat the inorganic component (soil) along with the combustible component. This is often the case for soils remediation.

Gases exiting the incinerator may require further treatment, depending on the composition of the waste stream being treated. Some possible treatment technologies for the air stream include afterburners, scrubbers, filters, and electrostatic precipitators (Sferrazza, 1990). Residuals produced by incineration include the cleaned soil and any ash that is produced. Exiting soil may be stored on-site, landfilled off-site, or may require further treatment if heavy metals are present.

Many different types of incinerating processes have been developed. Those appropriate for treatment of soils include, but are not limited to, the rotary kiln, fluidized bed, infrared, and

advanced electric incinerators. Of these, the rotary kiln incinerator has been the most widely used for soils treatment.

Applications

Incineration is widely used to treat organic contamination of solids. Some considerations that go into choosing the type of incinerator to be used are the contaminants present, the concentration of the contaminants, the type of material that is contaminated, and the volume of material to be treated. The technology is very effective for a wide variety of organic compounds and is most efficient for waste streams containing a high concentration of these compounds.

Sferrazza (1990) discusses incinerators used in the treatment of radioactive wastes. Soils and other radioactively contaminated solid waste materials can be incinerated to destroy any organic contaminants present and to reduce the overall waste volume which requires disposal. A variety of incinerator types have been employed at nuclear facilities around the country. These types include rotary kiln incinerators, air incinerators, plasma centrifugal reactors, natural draft incinerators, stationary grate incinerators, fluidized bed units, electrically heated incinerators, and stationary hearth incinerators.

Advantages and Disadvantages

The primary advantages of incineration are that it is very effective for most organic compounds and it is a well developed, proven technology. Some disadvantages are that the resulting streams (air and solids) may need additional treatment. It is not effective for inorganic compounds, and it is not as efficient for dilute streams. Additionally, some metals, such as mercury, may volatilize and leave the incinerator with the exhaust gas.

TECHNOLOGY DATA SHEET

VITRIFICATION

Description

Vitrification of wastes involves combining the wastes with molten glass at a temperature of 1,350°C or greater. However, the encapsulation might be done at temperatures significantly below 1,350°C (a simple glass polymer such as boric acid can be poured at 850°C). This melt is then cooled into a stable, noncrystalline solid (EPA, 1985).

One variation on this process is *in situ* vitrification (ISV) in which wastes and soils or sludges are melted in place to bind the waste in a glassy, solid matrix resistant to leaching. In the ISV process, four electrodes are inserted into the soil to the desired depth. A glass frit is placed between the electrodes to act as a starter path for the initial melt to form. As the melt grows downward and outward, it incorporates nonvolatile elements and destroys organic components by pyrolysis. The pyrolyzed by-products migrate to the surface of the melted zone where they combust in the presence of oxygen. Inorganic materials are dissolved into or are encapsulated in the melt. Convective currents within the melt uniformly mix materials that are present in the soil. When the electric current ceases, the molten volume cools and solidifies into a vitrified mass. A hood placed over the processing area provides confinement for the combustion gases, drawing the gases into an off-gas treatment system.

Applications

Vitrification is best used for soils with a high concentration of contaminants or with contaminants that must be completely immobilized (such as radioactive species). To be considered for vitrification, the wastes should be either stable or totally destroyed at the process temperature (EPA, 1985).

In situ vitrification will work with fully saturated soils; however, the water in the soil must be evaporated before the soil will begin to melt. Soils with permeabilities greater than 10^{-4} cm/sec are difficult to vitrify in the presence of flowing groundwater and, therefore, some type of groundwater diversion may be necessary. If buried metals, such as drums, occupy over 90 percent of the linear distance between electrodes, a conduction path that leads to electrical shorting between electrodes may result.

Several vitrification facilities for treatment of radioactive wastes are currently under development. The Hanford Waste Vitrification Plant is designed to fuse high-level radioactive mixed wastes into a glass product. The facility is expected to be completed by mid-1991. The Defense Waste Processing Facility will use vitrification for the immobilization of high-level waste from the Savannah River Site. This facility is almost complete, with cold testing scheduled for September 1990 and hot start-up planned for January 1992. The West Valley Nuclear Services Co. has constructed a vitrification system as part of the West Valley Demonstration Project. The vitrification system has completed a 5-year period of testing using simulated wastes and is currently being renovated. West Valley is preparing a Part A Radioactive Mixed Hazardous Waste permit for the facility (Sferrazza, 1990).

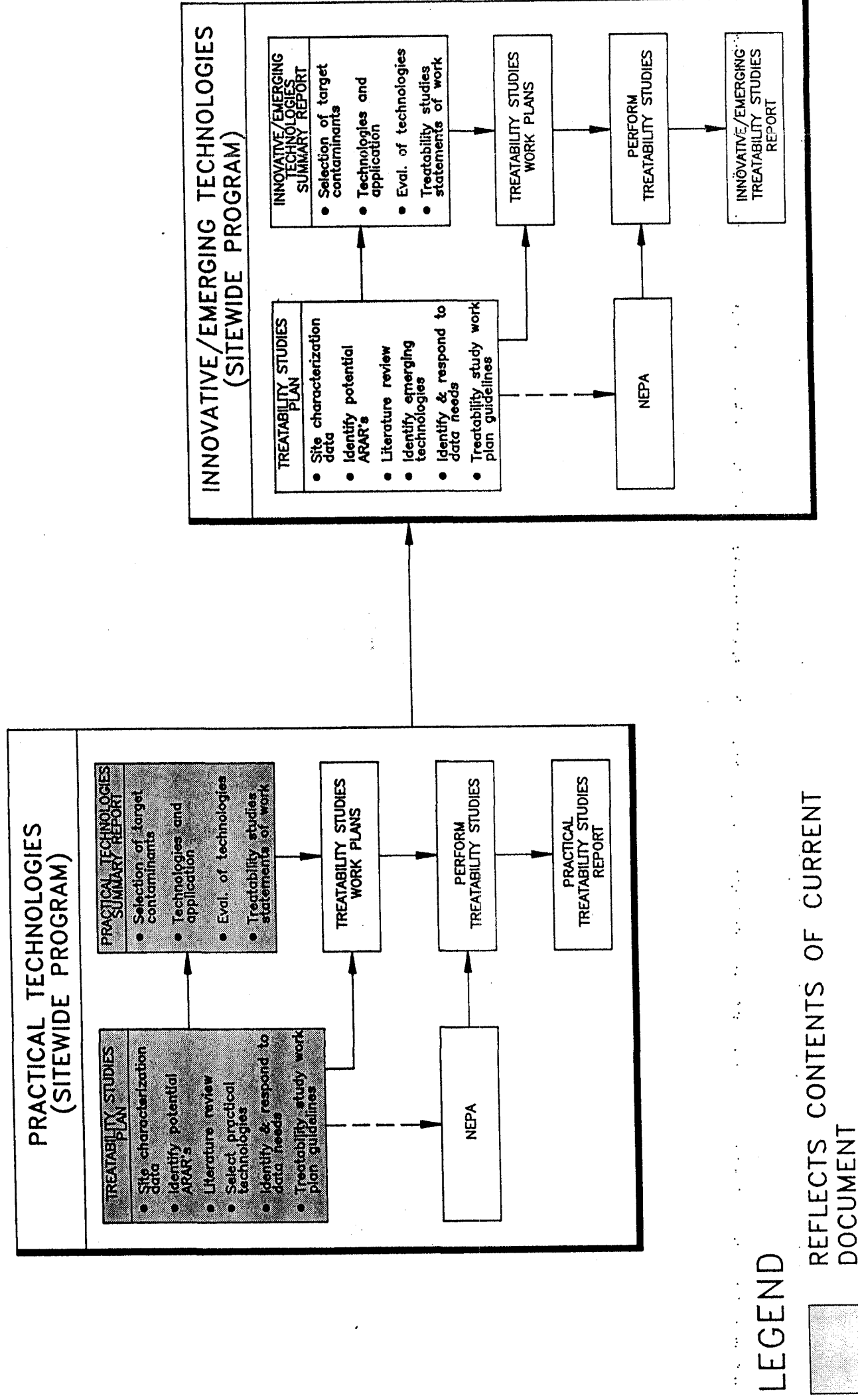
The Idaho National Engineering Laboratory is evaluating the feasibility of using *in situ* vitrification for treatment of buried wastes at this facility. The process has undergone laboratory and engineering scale tests at the Pacific Northwest Laboratory, where the equipment was developed, and has been applied once at the Idaho National Engineering Laboratory on a small test area. Starting in 1992, three larger scale tests are planned (Sferrazza, 1990).

Advantages and Disadvantages

The primary advantage of vitrification is that it effectively immobilizes nonvolatile species in a solid that is very durable and resistant to leaching. Disadvantages of this technology are related to its high cost, which is the result of the large amount of power that is required to melt the glass or soil and the need for specialized equipment and trained personnel (EPA, 1985). The presence of high moisture content or high organics may also hinder operation. Significant concentrations of combustible gases may also produce a safety hazard. This process may need an offgas collection and treatment system for volatile and semivolatile organics and volatile metals.

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FIGURE 1-1
ROCKY FLATS PLANT
SITEWIDE
TREATABILITY STUDIES PROGRAMS



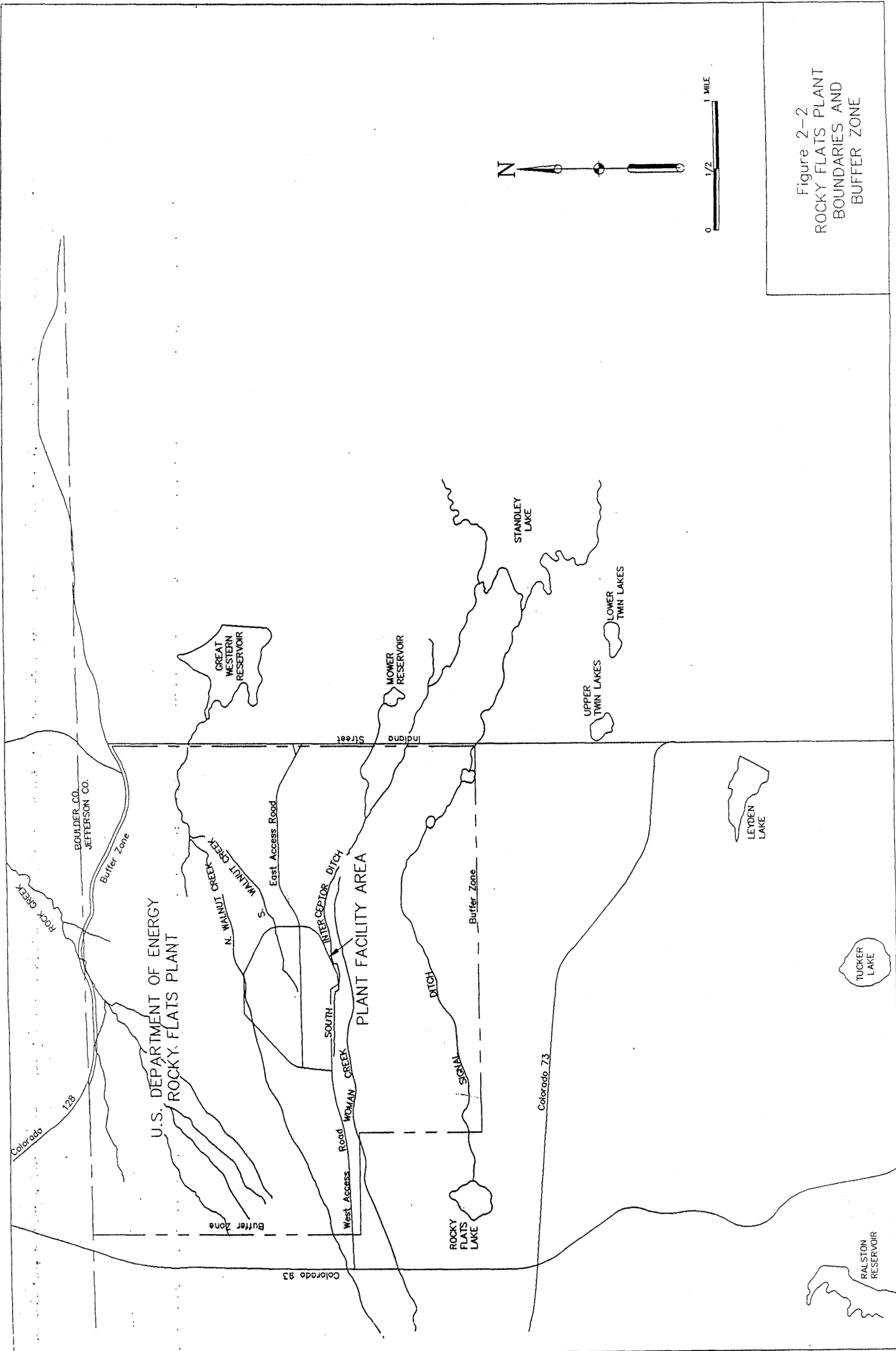


Figure 2-2
ROCKY FLATS PLANT
BOUNDARIES AND
BUFFER ZONE